THE DEVELOPMENT OF CRITERIA FOR THE QUANTITATIVE EVALUATION OF A UNIVERSITY SYSTEM

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THE DEVELOPMENT OF CRITERIA FOR THE QUANTITATIVE

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PREFACE

The reader should consider this study as an initial attempt toward quantitatively evaluating a total university system. In this context a university is considered as an abstract facsimile designed to approximate functions of a typical real university. A systematic search of the literature revealed numerous quantitative models of portions of the university. However, no models were found that attempted the unification of the overall system. In summary, the essential thrust of this research was to develop and simulate a generalized model of a localized university system.

This study continues and builds upon a more generalized anatomical view of a systems methodology proposed by Johnson (1). Of the first-order subsystems, this model considered facilities, organization, transformation, knowledge, communication, value, time, and dynamics. Six first-order subsystems--ethical, legal, moral, philosophical, power, and technology--were condensed and assumed constant to keep this work within the scope of a master's thesis.

Certain limitations were necessarily made in this attempt to evaluate quantitatively a system as complex as a university. One limitation was the design of a simulation model for a system as diverse as a university; however, if it is desirable to simulate a specific university system, the model can be modified for a more localized application. Another general limitation was the use of a model to represent an abstraction of some real system; therefore, a perfect relationship with the phenomenon was highly desirable but never actually achieved. This modeling prototype was limited to universities located in the United States. While there may be similarities to universities located in other countries, no attempt was made in this investigation to make this a world model.

Other constraints on this research were the mathematical formulation and the computer hardware and software which affected the simulation model. The mathematical expressions were formulated with the use of linear equations for a majority of the formulas and nonlinear ones for the remainder. Software limited the number of variables the computer system could manipulate and the reports it could output. The computer hardware had physical constraints on the amount of space available for storing data.

This method of research, however, had several significant advantages which it is believed outweighed the limitations. First, the total system was modeled with some simplifying assumptions. Second, the evaluation was quantitative; that is, all the system variables were quantified applying measurement theory and value theory. Third, it was built upon an orderly and systematic approach to modeling a complex system. Fourth, the simulation model generated valuable information about the operation of a university system. Finally, the study exemplified the engineering philosophy of contributing innovative and technological change to operating systems.

Several key definitions which appear frequently and link the chapters should be remembered by the reader. The first key word is "evaluation" which was defined as the process of examining or judging a phenomenon according to some set of appropriate criteria. A second key word, "measurement," was defined as the act of assigning numbers to objects or events according to some set of rules (2). The word "measurement," as used, is given the meaning it has normally had in scientific tradition. Third, "value," which is a multi-meaning word, was defined as an abstract criterion used to determine the importance or desirability between one or more units (3). The fourth key definition is "simulation" which was defined as a numerical technique for conducting experiments on a digital computer using certain logical and mathematical models which describe the behavior of the phenomenon over extended periods of time (4,5). The logical framework of the study is integrated by these four definitions.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

SUMMARY

The objective of this research was to design and simulate a prototypal model of a university system. The university system was decomposed into subsets which were evaluated separately and placed back together to consummate the whole system. Quantifiable criteria were developed as a basis for an objective evaluation. It was expected that all the variables could be measured at least on the ordinal scale, some on the ratio scale, and some few on the multi-dimensional scale.

Throughout the literature describing educational systems, the research was primarily limited to partial designs of the university system. Therefore, the first step of this research was to design a model for each subsystem of any general university system. Once the design of a subsystem was balanced, quantitative criteria were developed to evaluate it objectively. The summation of these subsystems resulted in a first phase design of a whole university system.

Measurement theory and value theory formed the basis and were integral cofoundations for developing quantitative criteria. A few of the variables were assumed to be measurable only on the ordinal scale, while most were assumed to be measurable on ratio scales. Value, based on the money criterion, was primarily used as the common integrator among all the subsystems.

Experiments on the model were run using simulation and real data collected from a pilot university system. The analysis revealed some

promising results. A university system can be modeled and a high percentage of the variables can be measured on the ratio scale; therefore, model credibility is confirmed at the prototypal level. The high computing efficiency of the simulation design provided a quick method of evaluating alternative solutions to decisions. This study, involving an attempt at innovative technological change in the university system, should open the possibility for further development in educational systems.

CHAPTER I

INTRODUCTION

The objective of this research was to design and simulate a prototypal model of a university treated as a system. Evaluative methods based on quantifiable criteria were applied in the simulation. First, the prototypal model was divided into subsets representing a facsimile of a general university. Second, quantitative criteria were developed using measurement and value theory for each subset, and finally, the whole university model was simulated.

Figure 1 shows the three primary hierarchical levels of the educational industry: elementary, secondary, and higher education. Each level is further partitioned to handle several different levels of human input. Throughout the entire structure the progression is primarily built upon a constant time-in-grade for each level with the resultant learning or development a dependent variable. While entry times to a level are constant, exit may occur after a minimal time in a grade or vary according to different levels once past the minimal levels. This study is particularly concerned with the more advanced, nonmandatory levels of education.

Human input to the educational industry has been growing at all levels. In 1961, 47 million students were enrolled in educational institutions of the United States as compared to 60 million ten years later (6). Also, the university as a system exhibits large-scale growth in human inflow. Total degree-credit enrollment has doubled

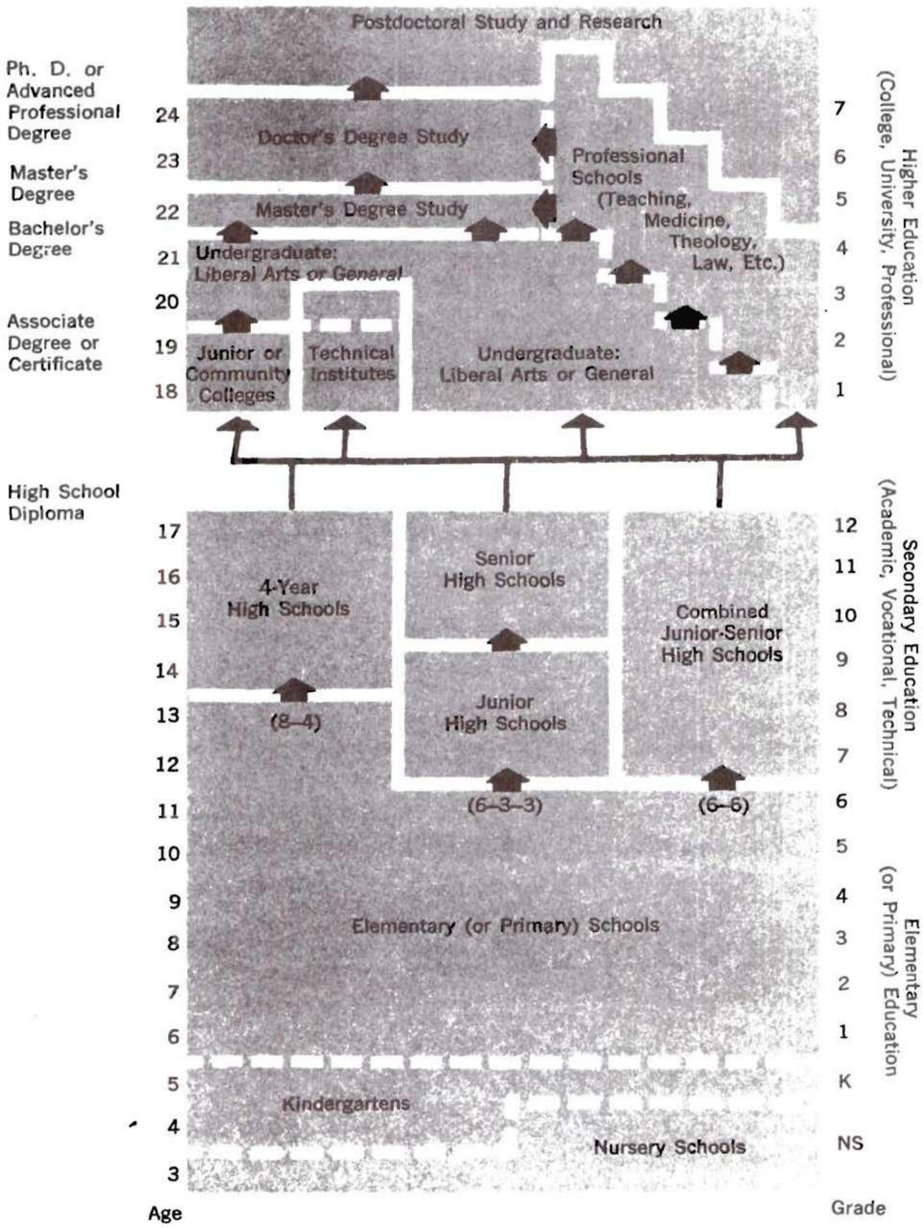

Figure 1. The Structure of Education in the United States. (Source: U.S. Office of Education, Digest of Educational Statistics.)

from the fall of 1961 to the fall of 1971, Figure 2. These growth trends in education followed the growth in overall population, the educational growth per individual, and a growth in accumulated wealth available for education.

In general, expenditures by all educational institutions have been increasing. Figure 3 shows this growing financial support. However, this growth in money expended in the educational industry has substantially leveled off in the last ten years (7). This leveling off is a natural evolvement resulting from a temporary exponential growth rate and a decreased rate of growth in birth rates.

Fluctuating enrollments and financial support in an expanding environment are dynamically related in the university system. From 1966 to 1970 enrollments were stable, but a decline occurred after 1970. A more detailed chart on the rate of change in university enrollments is illustrated in Figure 21 of Appendix D.

This research was focused on the university, the top level of the educational industry. The university was chosen because one of its prime missions is to innovate change, more so than any other level of the educational industry. Also, the university is primarily composed of a large body of consenting adults, each of which has discretionary choice in matters of change.

For this study the university was abstractly defined as a system. Fitz states,

> A system is
>
> a) a collection of diverse functional elements (which we call subsystems)
> b) which are organized into a structure of interaction and

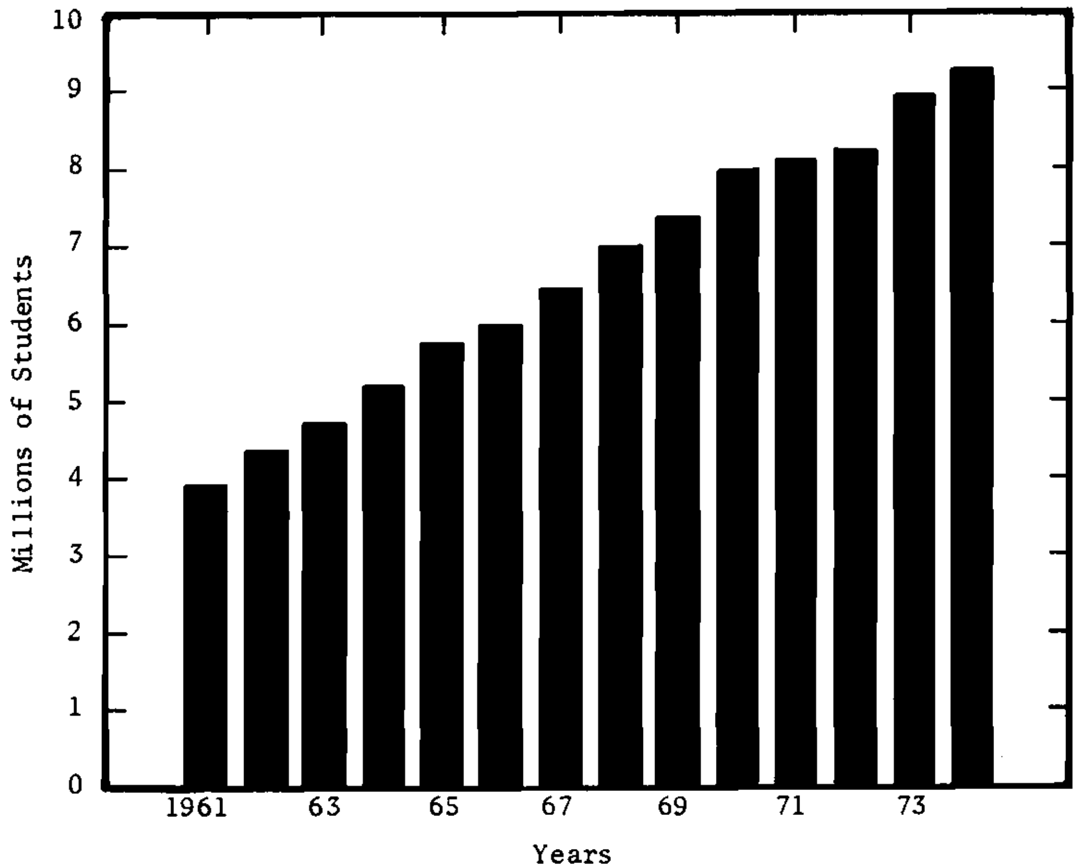

Figure 2. Total Degree-Credit Enrollment in Institutions of Higher Education: United States. (Source: Projection of Educational Statistics to 1981-82, National Center for Educational Statistics, 1972.)

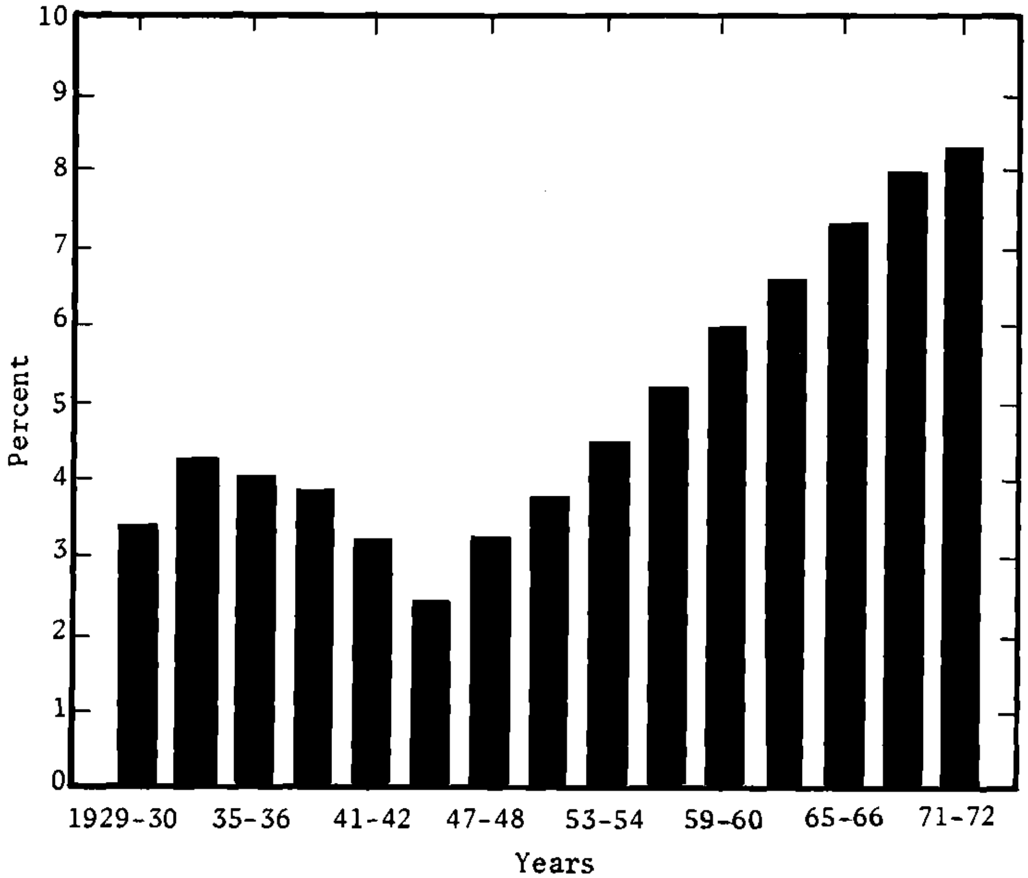

Figure 3. Total Educational Expenditures for Education as a Percentage of Gross National Product: United States. (Source: Standard Education Almanac, New Jersey, Academic Media, 1973-74.)

c) integrated into an environment
d) to achieve a desired goal
e) by processing inputs (matter-energy, or information) from the environment (8).

Based on the systems methodology referenced in the preface, the university system was separated and interrelated into fourteen subsystems: facilities, organization, transformation, knowledge, communication, value, time, dynamics, ethical, legal, moral, philosophical, power, and technology.

A closer examination of the university system revealed increasing system complexity. The concept of a complex system was not scientifically defined, although it refers in part to the number and kinds of components in the system and in part to the numbers of relationships between the components (9). From this conceptualization one can view the relationships within each component and the interrelationships between components.

The evaluative process was chosen as the critical focal point for the engineering methodology within this research. For this reason, quantitative criteria were developed to evaluate the university system. Other engineering methods such as planning and resource allocation models were prominent in the literature; however, evaluation was the primary approach to prepare a benchmark for future investigations.

Measurement theory was applied to quantify the variables in the university system. It established the meaningfulness of the numbers representing the system variables, provided there was a sufficient degree of isomorphism between the variables and the number system. For example, every number was unique and had identity; therefore, any variable to which a number was assigned had to have identity.

Identifying any variable meant precisely defining it by putting the variable on the nominal scale of measurement. A more meaningful measurement depended upon how many higher-order scales the measure could reach. There were three higher-order scales: ordinal, interval, and ratio. As a measure achieved higher-order scales, the theory permitted one to conclude more about the variables that were measured.

The other primary concept in this research was value. It was desirable to consider value based on the money criterion because it helps reduce complex value sets into simpler numeric sets. Value based on money was a common integrator among the components of the university system; therefore,it was chosen as a base for evaluating any subsystem.

Given the evaluative process and the theories of measurement and value, a model was chosen as the practical method of investigating the university system. The type of model chosen to represent the phenomenon was a simulation model. It was a facsimile of the university system which helped to understand the real system for simulation purposes. A model was easier to study than the full-sized system, because the relevant variables of the system were more apparent. Confidence in the model was established by validating its response in comparison to the real system's performance.

The evaluation was implemented by simulation. Simulation made it possible to examine more closely and define precisely variables that were naturally interactive and complex. Also, simulation made it possible to experiment with the internal operations of the university system. By making alterations on the system model, one could study the effects of certain informational, organizational, and environmental changes on the university's operation (10).

A research methodology is outlined in the following steps:

Step 1. Determine the system components; establish constraints on the system. Precisely define the system variables and transform inoperable ones such as knowledge, motivation, faculty, etc., to operable form for Step 3.

Step 2. Design models of each subsystem in the university system. Observing and understanding the system precedes the design phase.

Step 3. Apply measurement theory and value theory to the variables; initially put them on nominal scales, but always try to move up to a higher scale. Develop the quantitative criteria for evaluating the system.

Step 4. Design the simulation for the whole model of the university system. Test the model using artificial data.

Step 5. Refine the simulation model making any necessary alterations or modifications.

Step 6. Apply the simulation model to a selected university system; analyze the response of the simulation model and validate it.

Step 7. Make recommendations and conclusions about the research.

In summary, this chapter has stated the objective of this research and presented a profile of the educational industry. The university was defined as a system for scientific inquiry. Illustrated arguments were presented on the large-scale growth, increasing complexity, and dynamic and expanding environment of the university system.

CHAPTER II

LITERATURE SURVEY

The literature was surveyed in the fields of evaluation in the educational industry, theory of measurement, theory of value, and simulation. Major contributions discovered in this literature search are discussed below.

History of Institutional Research

Institutional research in higher education began in 1701 with the founding of Yale University. The Yale founders studied the problem of how to organize the college they envisioned. This study constituted one of the first known organized and published research findings of an institution of higher education.

Several other studies of institutional research were carried out in the eighteenth century. One individual of particular interest was Stiles who conducted three studies on the academic governing of an institution (11). In 1763-64, he helped design the government plans for Rhode Island University, later named Brown University. Before taking the presidency of Yale University in 1777, he investigated the controversy then going on between the Connecticut Legislature and the Yale governing board. After six months of concurrent investigation on the problems of Yale, he concluded his third study on their curriculum, entitled "Plan of a University."

The land-grant college act, or the Morrill Act of 1862, gave institutional research a significant change in direction (12). The Morrill Act provided for each state a grant of land equal to 30 thousand acres for each senator and representative from that state. These colleges were supported by the income received from the receipts set aside and invested as endowment. The Morrill Act states:

> . . . where the leading subject shall be, without excluding other scientific and classical studies, and including military tactics to teach such branches of learning as are related to agriculture and the mechanic arts, in such a manner as the legislature of the states may respectively prescribe, in order to promote the liberal and practical education of the industrial classes in the several pursuits and professions in life.

Farrell described the three major work categories of the land-grant colleges after twenty-five years of existence as resident instruction, research, and extension. Major developments of research were agriculture, engineering, home economics, chemistry, botany, and zoology. After World War II the land-grant colleges were no longer the principal beneficiaries of federal funds for research. According to Cartensen, large amounts of research money were distributed to defense establishments (13).

Until the development of advanced statistical methods in the early 1900s, meaningful educational research was stagnant. However, statistical concepts were employed by Eliot as early as 1869. He produced volumes of statistical tables in his annual reports on Harvard's operation. The first factual study of instructional methods was conducted by Eliot's successor, Lowell, in 1902. His study reviewed the system of working for honors and set the stage for Harvard's honors program. The honors program had a significant influence in helping change the attitudes of Harvard undergraduates toward serious study (14).

The development of research on the operation of universities became commonly known as institutional research. "Institutional research constitutes any thoroughgoing investigation of any topic concerning which a college or university or a group of them collects or seeks to collect data toward the end of improving operations" (15). Several of the topics investigated were academic government, class size, curriculum, college courses, instructional methods, student discipline, enrollment characteristics of students, teaching loads, faculty research, instructional costs, budgetary analysis, space utilization, and campus planning.

Harper, the first president of the University of Chicago, was a principal contributor to institutional research (16). Before being named president, he studied comprehensively higher education. Research in all appropriate fields of knowledge was the primary purpose during Harper's term in office. Promotions in rank and salary depended primarily upon "the merits of the research" they "carried out." Harper himself covered the whole gamut of education research from "the scientific study of the student" to "waste in education."

The concept of educational efficiency was influential on almost all important educational writers after 1899. The most important study of educational efficiency was sponsored by the Carnegie Foundation in 1910. It reported a study made by Cooke, a student of Frederick W. Taylor, who extended the notion of efficiency in engineering to a broader base of application. Its subject matter constituted "the cost and the output both in teaching and research in the department of physics" in six large universities and two small colleges (17).

Institutional research after the 1900s introduced the concept of self-studies. The concept of a formal institutional self-study unit, set up to study an institution on a continuing basis, was traced back shortly after World War II. Prior to 1955, only ten institutions of higher education had offices of institutional research. In existence today are some 250-300 such units throughout the country with the continuous study of a college or university as their primary purpose (18).

The work of institutional research units today is primarily concerned with academic questions. The first units of this type were established at the University of Illinois and the University of Minnesota. Minnesota's unit originated with the study of faculty problems, concerning the recruitment and retention of academic staff. However, in recent years the office, in response to university officials, has been gathering data on costs and other management problems. At Miami University of Ohio, the office of institutional research focused on carrying out studies on academic programs by serving as the secretariat for faculty committees. A typical project was a study of whether incoming freshmen would be more or less likely to earn a high grade in a subject if he or she selected the university's honors program. University of Washington experimented with student groupings in a dormitory to see whether the clustering of students by majors would increase the probability of successfully completing their academic careers. The University of Rhode Island devoted much time to institutional planning. Northern Illinois' unit advised the president during a five-year period on many of his key decisions directly from their studies (19).

Other major contributors to institutional research were agencies outside the university. For example, the Western Interstate Commission on Higher Education has developed a management information system. Various state coordinating and controlling agencies have contributed to studies of space utilization. Through its data collection and report system, the United States Office of Education was a strong force for standardization of definition and reporting. The AAUP (American Association of University Professors) has collected and reported data on salaries which has contributed methodology to both collection and utilization of comparative data (20).

Institutional research units have had primary responsibility to collect and analyze information on the effectiveness with which a college or university was achieving its academic goal (21). Institutional research studies arose from different sources: administrators, faculty, students, boards for campus control, and many agencies and individuals off the campus.

In summary, the literature on institutional research revealed that research has been conducted on the operations of university systems since 1701. Before 1900 institutional research had investigated these areas: organizing colleges, academic governance, establishing land-grant colleges, statistical studies, salary schedules and promotions, educational efficiency, and several other topics. After 1900, institutional research concentrated heavily on self-studies of a university system on a continuing basis. Several examples of self-study units and their principal work were found in the literature.

The most recent literature reveals that research was being conducted by several outside groups: Western Interstate Commission on Higher Education, American Association of University Professors, and state and federal coordinating agencies of the United States Office of Education. Overall the literature revealed a great interest in institutional research. However, since most of this interest occurred prior to the development of current formal systems methodologies, most of the material studied could be classified as general interest contributions rather than substantial scientific studies.

Major Federal Acts in Higher Education

The Morrill Act of 1862 was an important act in higher education, because it started the land-grant college movement in the United States. In 1887, the Hatch Act provided funds to the land-grant colleges to initiate agricultural research through the construction of experiment stations. The Second Morrill Act of 1890 provided annual federal expenditures to the land-grant colleges. More agricultural research was initiated with the Smith-Lever Act of 1914 which provided assistance to the farmers through state university agricultural extension services. Vocational and technical educational growth was stimulated by the Smith-Hughes Act of 1917. These acts were significant milestones in higher education because they strengthened the growth and provided guidance for directed research in the agricultural industry, the largest industry in the United States (22).

Most of the acts from 1920 to the present have provided financial assistance to the student so that the colleges had material to process. The National Defense Act of 1920 set up the reserve officers training corps on most land-grant college campuses. This act was a reaction by the federal government to World War I's absorption of the young men. These training programs by the army and navy accounted for as much as 50 percent of the college's income. In 1944, the Servicemen's Readjustment Act (G.I. Bill of Rights) provided servicemen financial assistance to attend colleges. It has been a vital source of assistance for the Korean and Vietnam veteran. Also in 1944, the government sold at large discounts millions of dollars worth of surplus military supplies and buildings to colleges through the Surplus Property Act. In 1950, the Housing and Home Finance Agency provided long-term loans to assist colleges in building dormitories. Congress created the National Science Foundation in 1950 to improve science and engineering (23). In 1958, the National Defense Education Act provided loans to students thereby emphasizing scientific education.

In 1963, the Higher Education Facilities Act supplied federal loans and grants for construction of dormitories and other academic facilities. The Civil Rights Act of 1964 was not as important to higher education as to secondary and elementary schools (24). However, higher education in the South was affected by admittance of blacks to several major state universities. In 1965, the biggest effort in higher education since the establishment of land-grant colleges was inaugurated by the federal government. The Higher Education Act was the most comprehensive national measure concerning colleges and universities since the Morrill Act. It provided federal assistance to all aspects of the university system.

The major federal acts in higher education shown in Table 1 were

Table 1. The Major Federal Acts Effecting Higher Education

1862	First Morrill Act--authorized land-grants to the states for the establishment and maintenance of agricultural and mechanical colleges.
1887	Hatch Act--federal government furnished annual appropriations of $15,000 to the states for the establishment of agricultural experiment stations at land-grant institutions.
1890	Second Morrill Act--provided for money grants for support of instruction in the agricultural and mechanical colleges.
1914	Smith-Lever Act--Congress authorized land-grant institutions to offer agricultural extension work in communities away from the campus.
1917	Smith-Hughes Act--provided for grants to states for support of vocational education.
1920	National Defense Act--set up the reserve officers training corps on most land-grant college campuses.
1944	Servicemen's Readjustment Act--provided assistance for the education of veterans.
1944	Surplus Property Act--authorized transfer of surplus property to educational institutions.
1950	Housing and Home Finance Agency--authorized loans for the construction of college housing facilities.
1950	National Science Foundation--was created to improve science and engineering through institutes for colleges and other teachers.
1958	National Defense Education Act--provided assistance to state and local school systems for strengthening instruction in science, mathematics, modern foreign languages, and other critical subjects; provided higher education student loans and fellowships.
1963	Higher Education Facilities Act--authorized grants and loans for classrooms, libraries, and laboratories in public community colleges and technical institutes as well as undergraduate and graduate facilities in other institutions of higher education.
1965	Higher Education Act--provided grants for university community service programs, college library assistance and library training and research; strengthened developing institutions, and educational opportunity grants; insured student loans; provided teacher training programs, and undergraduate instructional equipment; established a National Teacher Corps and provided for graduate training fellowships.

surveyed in the literature. These acts significantly affected the behavior of the university system from 1862 to the present time. A comprehensive treatment of the major federal acts in higher education was found in the literature.

Evaluation in the Educational Industry

The growth of the university system in the United States increased the demand for examining the effectiveness of the system's operation. Tighter controls were implemented on university operations to stabilize the growth in costs of university operations. One of the more recent suggested trends toward control was "accountability" which is the principle of answering to the public in terms of results. It was introduced initially by Lessinger who extended it as a solution to the public in terms of not only how schools should spend their funds, but also of what educational gains they could achieve (25). Criteria should be developed to evaluate the spending of large sums of money. Accountability in education coincided with public accounting practices in business and industry. The introduction of accountability as a control for operational costs in educational systems created a further need for organized evaluation in this system.

The operational effectiveness of higher education was a subject of national interest and concern in 1947, as described by Pace and Wallace (26). In 1947 a comprehensive treatment of this topic was reported by the President's Commission on Higher Education. Pace and Wallace stated that over a period of fifty years or more the methods of educational measurement had been developed and refined. The current state of the art in evaluation methods was well represented in the

1950s by Lindquist (27). Most of the evaluations conducted during this period were self-study types for the North Central Association of Colleges and Secondary Schools. Russell gave a historical perspective of accrediting policies and practices (28). Criteria considered by North Central in its accrediting procedures included the following: purposes and clientele of the institution, faculty, curriculum, instruction, library, student personnel services, administration, finance, physical plant, institutional study, and athletics (29).

Since 1954 the growing concern about quality in higher education, the support of institutional self-studies, and the Fund for the Advancement of Education have all contributed to a heightened interest in evaluation research. Stuit summarized the feeling of most educators in stating "that an institution should be evaluated by the quality of its products" (30). He suggested several techniques to measure these dimensions: psychological tests, standardized achievement tests, student opinion on assessment of teaching, alumni success, and amount of salary earned by professors. The evolution of educational evaluation until the 1960s was described by Stuit.

Self-studies were largely the product of committee discussions and hearings conducted by faculty members and outside consultants. Dressel and Dietrich described the self-study of departments at Michigan State University (31). They stated:

> . . . the typical approach in the medium-sized or large institution was to engage in a study of purposes, objectives, and functions of the university as a whole. It was left largely to the colleges and departments to review their own activities in the light of the general analysis and recommendations made by the self-study committee. Thus, it happened regularly that despite programs of institutional self-study, many units in the university changed little or not at all.

A movement toward a comprehensive evaluation of the university system was described by Stake (32). In shaping an educational program, he discussed the need for methods in which judgment data could be measured. In 1968, Glass wrote:

> The current meaning of the term "evaluation" in several recent writings and in federal legislation is that it is the gathering of empirical evidence for decision-making and the justification of decision-making policies and values upon which they are based (33).

Evaluators were aiming toward the central problem in evaluation. They indicated there was a need for measurement in decision-making.

More recently, Sjogren stated that evaluation theorists indicate that evaluation should attend to the input-process-outcome (34). He also stated that there were problems in implementing the input-process-outcome evaluation. The inclusion of the many variables in a comprehensive evaluation required a massive amount of measurement and classification. Also, there were problems associated with obtaining valid and reliable measurement and classification of a great many variables, including many not traditionally considered in evaluation methodology.

Some recent techniques in econometrics were being applied in educational evaluation through cost-benefit analysis. Blauf and Alkin discussed many of the problems associated with the measurement of costs (35). According to Sjogren the measures were not well developed because such variables were not recognized as important in evaluation.

Typically, measurement of outcomes have been considered by educational economists. The works of Kotz, Warmbrod, and Thomas were excellent sources for examining the relationship of certain economic concepts to educational evaluation:

(a) What benefits accrue to both the individual and society from the program?
(b) Investment return and the consumption returns of the program?
(c) "Shadow" benefits of the program, i.e., noneconomic benefits?
(d) Trade-offs, i.e., what did the person not learn by being in this program instead of another?

The recent theories of evaluation in the university system were focused on the real problem of measurement; that is, defining the systems variables.

The development of measurement and evaluation in the educational industry began with the Chinese in 2200 B.C. Their civil service examination, stated Green, measured human variability (36). Also, Socrates initiated the oral examination in his teaching method. In 1215, the oral thesis examination was introduced at the University of Paris to evaluate a candidate's competence. According to Green, the popular growth of psychological measurement and experimentation took place from 1850 to 1930. During this period a milestone was achieved in mathematics applied to measurement by Galton's book, Hereditary Genius. Rice made up the first standardized test in 1897. A major contribution to the testing movement was the achievement test developed by Thorndike. He proposed several principles which are still used in constructing standardized tests: (1) scaling test items according to difficulty, (2) objectively scoring tests, and (3) tests having statistical norms. Aptitude tests were pioneered in 1919, and major revisions were stimulated by Thurstone in 1939. The literature in the sixties and early seventies revealed similar facts in educational measurement and evaluation. Measurement was confined to measuring human variability through tests.

Another kind of evaluation was mentioned in the literature as school plant evaluations. The technique generally involved collecting data on score cards and comparing them to generally accepted standards for school facilities. An example of a score card was in Odell, Standards for the Evaluation of Secondary School Buildings (37). The score card was based on a thousand-point scale, and the adequacy of a building was judged by the total number of points which it received during a survey. A building receiving 850-1000 points was in excellent condition while one receiving 400 or less was unsatisfactory.

Evaluation of human and psychological variability dominated the literature. Its past and recent history was well documented. Sjogren stated the need exists for a broadened concept of educational evaluation (38). He continued by stating that this broadened concept required measurement and classification procedures for nonpsychological variables. The literature recorded suboptimal models in quantitative evaluation methodologies of a university system.

Theory of Measurement

Campbell was recognized as the classical theorist of measurement in the physical sciences until the 1930s (39). He defined measurement as "assigning numbers to objects or events according to a set of rules" (40). The classical view of measurement, as Campbell presented it, was essentially the view that "fundamental measurement is possible only when the axioms of additivity can be shown to be isomorphic with manipulation performed upon objects" (41). This widely accepted view held that "the assignment of numerals to objects other than by the procedures involved in fundamental measurement was not measurement at all" (42).

A more general theory of measurement than Campbell's was developed by Stevens in the 1940s. Stevens' approach classified scales of measurement in terms of the group of transformations that left the scale form invariant. The four scales, which are described in Table 2, were called nominal, ordinal, interval, and ratio (43). For example, to erect an interval scale one needs a procedure for equating intervals or differences and a procedure for determining equality or equivalency. Table 3 contains the three properties of measurement: identity, rank order, and additivity. These properties distinguish the four scales (44). The higher the scale, the more statistical and mathematical operations could be accomplished with the numbers defined from measurement.

In recent years there has been an increase in the attention to all types of measurement as an aid to management. Along with management accounting it became evident that more attention should be given the changing value of the dollar measuring unit. Measurement in financial accounting was largely the province of the certified public accountant (45). The educational industry felt a similar need for management accounting and educational program accounting. Accountability was a strong ingredient in the operation of the university system because it emphasized measurement. This record in the literature substantiated the necessity of measurement in evaluation applied to the university system.

The theory of measurement was established in the literature applied to physical systems. Invaluable insight into measurement theory

Table 2. A Classification of Scales of Measurement*

Scale	Basic Empirical Operations	Mathematical Group Structure	Typical Examples
Nominal	Determination of equality	Permutation group $x' = f(x)$ where $f(x)$ means one-to-one substitution	"Numbering" of football players. Assignment of type or model numbers to classes
Ordinal	Determination of greater or less	Isotonic group $x' = f(x)$ where $f(x)$ means any increasing monotonic function	Hardness of minerals Street numbers Grades of leather, lumber, wool, etc. Intelligence test raw scores
Interval	Determination of the equality of intervals or of differences	Linear of affine group $x' = ax + b$ $a > 0$	Temperature (F or C) Position Time (calendar) Energy (potential) Intelligence test "standard scores"
Ratio	Determination of the equality of ratios	Similarity group $x' = cx,$ $c > 0$	Numerosity Length, density, work, time intervals, etc. Temperature (R or K) Loudness (sones) Brightness (brils)

*Measurement is the assignment of numerals to events or objects according to a set of rules. The rules for four kinds of scales are tabulated above. The basic operations needed to create a given scale are all those listed in the second column, down to and including the operation listed opposite the scale. The third column gives the mathematical transformations that leave the scale invariant. Any numeral x on a scale can be replaced by another numeral x', where x' is the function of x listed in column 3.

Table 3. The Properties and Axioms of Measurement

Axioms	Properties
1. Either $A = B$ or $A \neq B$ 2. If $A = B$ then $B = A$ 3. If $A = B$ and $B = C$, then $A = C$	Identity
4. If $A > B$, then $B \ngtr A$ 5. If $A > B$ and $B > C$, then $A > C$	Rank Order
6. If $A = P$ and $B > 0$, then $A + B > P$ 7. $A + B = B + A$ 8. If $A = P$ and $B = Q$, then $A + B = P + Q$ 9. $(A + B) + C = A + (B + C)$	Additivity

was found in the literature. The establishment of measurement theory was one basis of this research for quantifying the variables of the university system.

Theory of Value

Johnson states that "value is an abstract perception of importance or desirability between one or more units" (46). It has evolved as a multi-meaning word that is intended to provide criteria for making decisions between alternative courses of action. One extension of the value notion is the fundamental first step for building an exchange structure that helps one in everyday patterns of operation. According to Hall, "value resides in any set of interest, or appreciation of an object, event, or state of affairs" (47). Davidson, McKinsey, and Suppes considered that the general function of value theory is to provide formal criteria for rational decisions, choices, and evaluations (48). These three authors conceived that it is perfectly correct to use value theory to define necessary formal conditions for rational choice.

Economic values, such as value-in-use or subjective value, value-in-exchange or market value, and imputed value or estimated market value were discussed by Hall (49). There are tangible values which have "responded to traditional measurement" and intangible values which are not "easy to identify, measure, or make comparative judgments" (50). Also there is value associated with different points in time, and long-term values, such as gold, silver, and land. Another type of value is utilitarian value which can be utilized or consumed rather than preserved (51).

Hall discussed economic value, psychological value, statistical decision-making and gaming, and casuistic value in more detail. These theories cover a wide range of value systems and demonstrate how value has evolved into a multi-meaning concept.

The value concepts used in this study were particularized and defined for each developmental part of the design. Value, based on the money criterion, was utilized throughout this study. Johnson states,

> Money is a concept invented and developed as a criterion to represent value. Its primary purpose is to give value a reference scale so that mathematical computation and comparisons between goods can be made. (52)

The money criterion, when well-formulated, serves the four basic traditional purposes: a standard of value, a medium of exchange, a store of value, and a standard of deferred payment.

In summary, the literature gave several meanings for value: rational preference ranking, tangible, intangible, economic, long-term, utilitarian, psychological, statistical decision-making and gaming, and casuistic. Value based on money was an acceptable criterion in which to determine the importance between one or more arbitrary units. Other value theories were presented by Hall, but money helps reduce complex value sets into a simpler criterion for evaluating any system. Value theory was well-documented in the literature. Along with measurement theory, it provided a fundamental basis for its application in this study.

Models

A model is a broad concept used as a replica of the phenomenon considered (53). It is used to represent an abstraction of some real system for purposes of prediction and control (54). The model itself is regarded as arbitrary since it represents something its creator desired. There are two classes of models, real and abstract. Real models consist of physical models. All others are abstract models: conceptual, verbal, graphic, photographic, symbolic, mathematical, statistical, and simulation.

Primarily this study utilized conceptual, verbal, symbolic, mathematical, and simulation concepts of modeling. For initial validation, simulation was used to relate the abstract developments to a physical model of a sample real university. Also simulation was the most pragmatic modeling approach for studying the operation of the university system because it can handle the large number of variables in this system.

A big advantage of a model is that it provides a frame of reference for studying the phenomenon. Abstraction could be represented at any desired level. Models suggest preliminary experiments to determine which characteristics are relevant to the particular decision under consideration. Their usefulness is proportional to the goodness-of-fit between the performance of the original phenomenon and the replica (55).

Simulation

Machine simulation existed both as a concept and as an operational technology long before general-purpose computers were developed. Figure 4 shows the distribution of publications from a bibliography of simulation studies prepared by Dutton and Starbuck, published in 1971 (56). The very earliest publications described practical, if unbuilt, mechanical devices.

The general-purpose computer facilitated the satisfaction of potential modeling demands in the early fifties. It reduced time and dollar costs of modeling and permitted the construction of complex models. The communications media were influenced by computer languages. Simulation was aided by new statistical computations and analysis was more productive and meaningful. More complete investigations were undertaken because the computer provided faster operating time.

In the late 1940s according to Naylor, von Neuman and Ulman originated Monte-carlo analysis to solve unclear shielding problems of the Manhattan Project (57). The problems they analyzed were too expensive for experimental solution or too complicated for analytical treatment. Subsequently, the capability of the computer was fully recognized and proven successful as a potent machine in the Manhattan Project.

"Man's unceasing quest for knowledge about the future" was the fundamental rationale for emphasizing simulation, stated Naylor (58).

Prior to the seventeenth century purely deductive methods were used by such philosophers as Plato, Aristotle, and Euclid. However, in 1620, Bacon became the first philosopher to recognize the limitations of deductive logic in predictive knowledge, and said, prediction must include methods of inductive logic (59).

Presently, the scientific philosophy or the scientific method consists of four well-known steps: (1) observation, (2) formulation of hypothesis, (3) prediction of the system behavior, and (4) testing for validity.

Simulation may be substituted for any one of the four steps in the scientific method (60). Some reasons for substituting simulation were that it may be too costly to observe real processes in the world; the complexity of the system does not allow an analytical solution; validating experiments on the mathematical model may be too costly; the complexity of the system precludes a mathematical representation (61). Simulation made it possible to apply scientific method to a complex system.

Summary of Literature Survey

The literature did not reveal substantive evidence that criteria for a quantitative evaluation of a university system have been developed. However, the literature revealed extensive and substantial research on measurement theory and value theory. Simulation was well covered in the literature; consequently, extensive help was found for this part of the research. The important conclusion substantiated by the literature search was the void in developmental research on the quantitative evaluation of the university system.

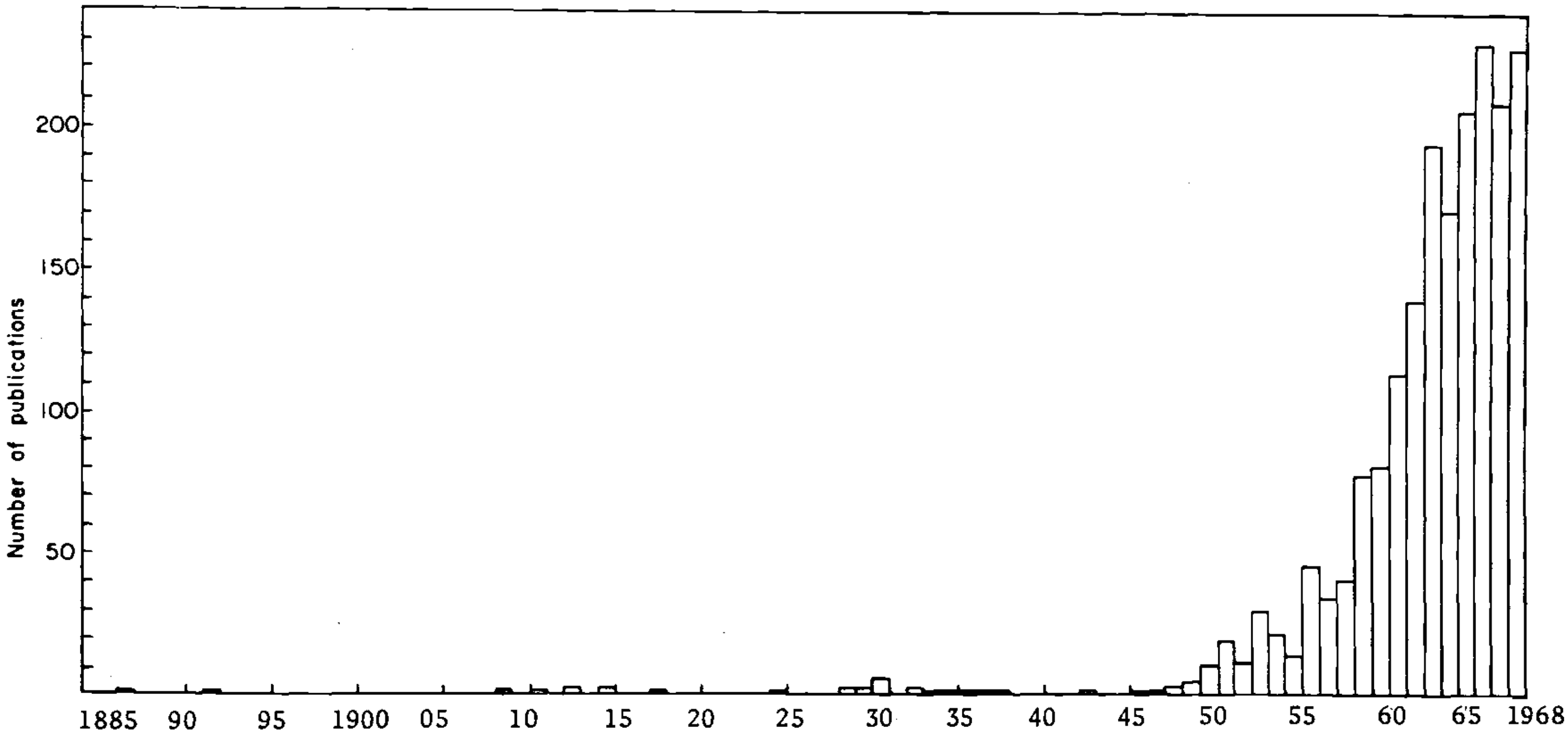

Figure 4. Time Distribution of Simulation Publications

CHAPTER III

DESIGN OF A UNIVERSITY SYSTEM MODEL

Approach

The approach was to design the model for each subsystem of the university system. Once the design was balanced, then the next step was to develop criteria for the quantitative evaluation of the system. Measurement and value theory were applied in the development of criteria.

University System Model

The university system was artificially enclosed for study using a systems methodology. It was isolated so that the boundaries of the system were definable for this study. There were fourteen subsystems constituting this system: facilities, organization, transformation, knowledge, communication, value, time, dynamics, legal (static), ethical (static), moral (static), philosophy (static), power (static), and technology (static). The university system was defined using a systems methodology, which systematically simplified the complex phenomenon into its first-order internal subsystems.

Facilities

The facilities subsystem was the first level in modeling the university system. Facilities were composed of land, buildings, equipment, and $\text{people}_1, \text{people}_2, \ldots, \text{people}_n$ (except students), who were classified for design purposes. In designing the model, land was the foundation of the whole university facilities subsystem; all the components overlay land. After land, the next level was buildings, and the interrelationships of land and buildings were modeled. Equipment was the third level overlaying buildings and people were the fourth level in the facilities subsystem.

The approach used in modeling the land component was typical of that used in the other components of facilities. An experimental piece of university land was encapsulated for study by placing a grid overlay similar to any topographical map. The grid was an X × Y cartesian coordinate system, X the abcissa and Y the ordinate axes. Each grid represented one acre or 43,560 square feet.

This grid model separated the land into parcels from which one could analyze the system in an orderly manner. In constructing the grid overlay of land, this rule was followed consistently: a rectangular or square overlay must be constructed that encompasses all the land of the university, central campus and any dispersed land parcels.

Each grid contained a multiple summation of land, buildings, equipment, and people.

$$\text{Grid } r = \sum^{r} (\text{Land} + \text{Buildings} + \text{Equipment} + \text{People})$$

Each component of facilities added another level to the system.

Several variables were designed into the land model. Size of the land component in a university was the principal variable. Other variables were the location of the land, external appearance or the height dimension, utilization, centroid of the central campus, distance of each land parcel to the centroid, degree of contiguity, and degree of compactness. It was stated that value was the common integrator in every subsystem. Therefore, value was introduced as market value in this first system level, and it overlays every subsystem in the university system (62).

Buildings constituted the second level of facilities. Space was the primary variable investigated in buildings. There were two types of space variables modeled; the first type was volumetric space and the second type was area space. Volumetric space was a more important variable in a facility; therefore, it was modeled in more completeness. It was defined by twelve categories:

I. LECTURE--space designed for the purpose of discourse before a class or group of people.

II. LAB--space designed for the purpose of conducting scientific experiments and special instruction.

III. ALL OTHER SPACE--space designed as part of the university system operations which cannot be defined under any other category; e.g., central receiving, bus stops, squares, parks.

IV. STUDENT SERVICE--space which was occupied by counseling, health and food services, job placement, student center, and church affiliated organizations.

V. PHYSICAL PLANT--space which was occupied by the custodial, grounds, maintenance, and power plants of the system.

VI. ADMINISTRATIVE--space which was occupied by the management and information-control subsets of the system.

VII. FACULTY--space occupied by the faculty of the system.*

VIII. ATHLETICS--space which was used for collegiate sports or recreation by the students and faculty of the system.

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*Faculty were defined as anyone whose primary functions were to teach-advise and conduct research.

IX. HOUSING--space which was occupied by the student population for living quarters.

X. ROADWAYS, WALKWAYS, PARKING--space designed to accommodate the transportation network of the university system.

XI. TECHNOLOGICAL--space which was occupied by the computer technology and research of the university system.

XII. LIBRARY--space which was occupied by information-processing, retrieval, and storage for the university system.

All university building space was categorized into one of these twelve subsets of the volumetric space variable.

The second type was area space which was defined as the amount of land area occupied by a building. Area space was especially important for developing criteria on the interrelationship of land and buildings. A second interrelationship between these two components was the grid model, which was already described.

Other variables designed into this model were height, chronological age, and space value based on replacement cost.

Equipment was the third component of the facilities subsystem. Its variables overlay the other two components: land and building. One variable introduced initially in this model was mobility. Mobility was defined as the movability attribute of a unit of equipment. A unit of equipment was highly movable if it was transferred in and out of the university system; it had average movability if transferred in and out of a grid; and immovable if it remained inside a grid. These three criteria identified the mobility factor for a unit of equipment.

Two other important equipment variables of this model were the surface area (or floor area) occupied by the equipment and the unit value for the equipment. Surface area demonstrated the interaction between equipment and buildings. It permitted a comparison between equipment per square feet of floor space and later, people per square feet of floor space. A further interrelationship between buildings and equipment was represented by two variables from the building component: the number of buildings per grid and the total building volumetric space per grid. The second variable, value based on replacement cost, represented the value overlay on equipment.

Seven categories were provided for classifying equipment units:

I. TECHNOLOGICAL--equipment used to maintain the research and computer technology of the university system.

II. INSTRUCTIONAL--equipment used for the purpose of presenting lecture material to classes and laboratory experiments.

III. ADMINISTRATIVE--equipment used by administrative employees (including faculty) of the university system; i.e., typewriters, copying machines, cash registers, adding machines, office desks, communication equipment.

IV. PHYSICAL PLANT--equipment used to maintain the physical plant, grounds, and all other maintenance of the university system.

V. ATHLETIC--equipment needed to maintain athletic facilities, players and their physical condition, and intramural facilities for student, faculty, and all other people of the university system.

VI. STUDENT SERVICE--equipment used for housing, health, food preparation, and communication needs of the students in the university system.

VII. LIBRARY--equipment used to maintain the information-processing, retrieval, and storage for the university system.

All equipment units were exclusively classified into one of the seven categories.

Because equipment was a component of the facilities subsystem, the grid model was an orderly approach to assigning equipment to a specific location. This approach contributed several important criteria to the evaluation.

The fourth component in the facilities subsystem was people. Up to this point the land, buildings, and equipment components have been discussed along with their interrelationships. The people component (excluding students) overlays the other three and interacted with them as represented by the variables designed in this part of the model. Modeling people was similar to modeling equipment, except people were more mobile; therefore, people exhibited a higher mobility. The same criteria were used for people to identify their mobility factor. People, the fourth component, completed the facilities subsystem.

Besides the mobility variable some other new variables were introduced. These new variables were the number of people absent from the grid, the average number of daily hours that people occupied their assigned space, the average number of hours people worked, the number of years affiliated with the system, chronological age, and the educational background of the people. Two input variables were interrelated with the building simulation: the square feet of building volumetric space per grid and the number of buildings per grid. From the land simulation, the square feet of land per grid was an input to this model. One could abstractly visualize the people component overlay on the other components by the facilities model.

People were classified into ten categories according to the common variable of market value. The ten categories were:

I. $\$ \quad 0 \leq P22 \leq \$ \ 4,000$

II. $\$ \ 4,000 < P22 \leq \$ \ 8,000$

III. $\$ \ 8,000 < P22 \leq \$12,000$

IV. $\$12{,}000 < P22 \leq \$16{,}000$

V. $\$16{,}000 < P22 \leq \$20{,}000$

VI. $\$20{,}000 < P22 \leq \$24{,}000$

VII. $\$24{,}000 < P22 \leq \$28{,}000$

VIII. $\$28{,}000 < P22 \leq \$32{,}000$

IX. $\$32{,}000 < P22 \leq \$36{,}000$

X. $\$36{,}000 < P22$

Each category was also identifiable by the type of people that fell into the salary range. This identification was useful in later sections of the system model. Another method for naming these salary ranges was a state salary schedule for employees. This method would not work for all universities, but it would be effective where applicable.

All people (except students) in the system fell into one of these categories.

The facilities model was designed using the four components; land, buildings, equipment, and people. A grid model, which resembled a topographical map, overlays the land component. This design permitted an orderly evaluation of the facilities subsystem, because the four components were summed for each grid. Once every grid was analyzed, the facilities subsystem became a summation algorithm.

Organization

The organizational subsystem was the configuration which collected and dispersed the power of the system in an orderly manner. In the university system this configuration overlays the whole system and channels the power flow and describes the deployment of it. Power was the central force of the system which transferred the needs and desires of the population from the exterior systems to the inner controlling system. Recall the power subsystem was defined to remain static. The organizational subsystem was a subsubsystem of power; therefore, it became the charging, discharging, and transformation device for the subsystem.

This design implemented three anatomic components of the organizational subsystem. First component was the structure of the organization based on the theory of equality-inequality (63). The organizational structure was designed applying the three-dimensional mathematical model.

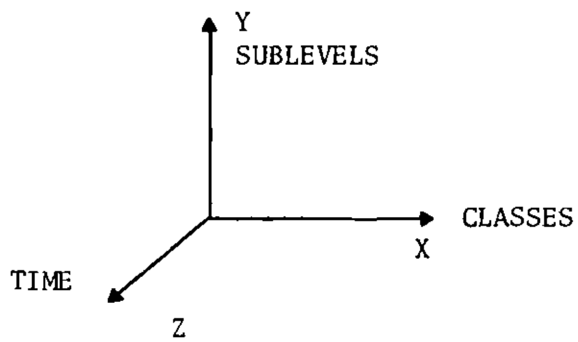


Figure 5. Organizational Subsystem Model

The configuration overlaying the university consisted of seven classes (x-axis): president, vice-president, deans, department directors, faculty and staff, housekeepers, and students. These classes were divided into sublevels (y-axis) based upon the market value associated with the people constituting the classes.

According to the theory of equality-inequality, inequality was represented by the y-axis, equality by the x-axis, and the z-axis represented time. An example of the y-axis was the president's level, based on the market value criterion. This power was measurable on the ordinal scale. Equality was described by this example: full professors had more power than assistant professors based on the market value criterion. One could conceptualize the organizational configuration using the theory of equality-inequality. Adding the time axis, third dimension, described the dynamics of the configuration.

The second component was centralization-decentralization of the organization (64). A centralized organization was one which had a high density or degree of clustering of people in a geographic location. The power function was concentrated in one specific center. A decentralized organization was typically one where people were geographically dispersed. The power function was spread where several centers deployed the flow. This component was measurable on a ratio scale. Centralization-decentralization was concerned with the geographic clustering and dispersion of people.

Applying a procedure to this definition of centralization-decentralization enabled one to measure this organizational component. Three steps were presented to arrive at a measure of the centralization-decentralization index.

Step 1. Determined the population of the system and the high density locations.

Step 2. Estimated the number of population centers within the system area and drew a boundary around them using an approximate centroid.

Step 3. Calculated the total circular area occupied by the system, given the average radius (in miles) from the centroid to the boundary.

It was important to follow these steps because the resultant was a measure of the physical circular area (square miles) where the organization was located. This measure quantified the centralization-decentralization variable of the organization. The smaller circular area indicated a centralized organization because it was a more clustered system. On the other hand, the larger circular area indicated a decentralized organization because it was a more dispersed system. Again this was only one procedure to measure the centralization-decentralization variable of the organizational subsystem.

The third component was the motivational element in the organization. Organizational motivation permeated the subsystem causing strong interrelationships among the components. A motivated subsystem was assumed to be highly active. Different motivational factors considered were the number of students applying to the system, research money obtained through outside funding, the number of recruiters seeking the system's product, and the number of earned-degree students outflow. All factors were measured on ratio scales. Motivation, measured by variables that were defined above, carried the organization to higher goals.

Three anatomic components of the organizational subsystem were modeled: hierarchical structure based on the theory of equality-inequality, centralization-decentralization, and motivation. The structure was the three-dimensional mathematical model representing sublevels, classes, and dynamics of an organization. It was the energizing, deenergizing, and transformation device for the subsystem's power function. The organizational subsystem was a configuration overlaying the whole system and providing the network for the flow of power.

It should be noted that the equality-inequality, centralization-decentralization, and motivation components demonstrated the design methodology on the organizational subsystem. More components existed, but they were treated as static. This constraint enabled a balanced systems approach which allowed a total systems design.

Transformation

The transformation subsystem processed students through a positive change from State A to State B. Change in knowledge, social effectiveness, and psychological behavior occurred at every state of the transformation process. The transformation subsystem overlays the facilities and organizational subsystems, and interacted with them by transforming raw input into a socially effective product. The transformation subsystem utilized the input-transformation-output relationship in systems design. First, the transformation subsystem was divided into its smallest part, called a state. A prescribed number of states made up a whole transformation period for a student. A state represented a ten-week time period, assuming a quarter system, or a different interval for other systems. Each state was a microscopic design of the input-transformation-output relationship. The transformation subsystem processed input from State A to a product in State B such that State B was greater than State A.

Figure 6 shows a system flow model of the transformation subsystem. The design applied the input-transformation-output technique which permitted a logical design of the transformation subsystem. Input to the first stage was made up of student physical flow and value. The transformation phase included the student

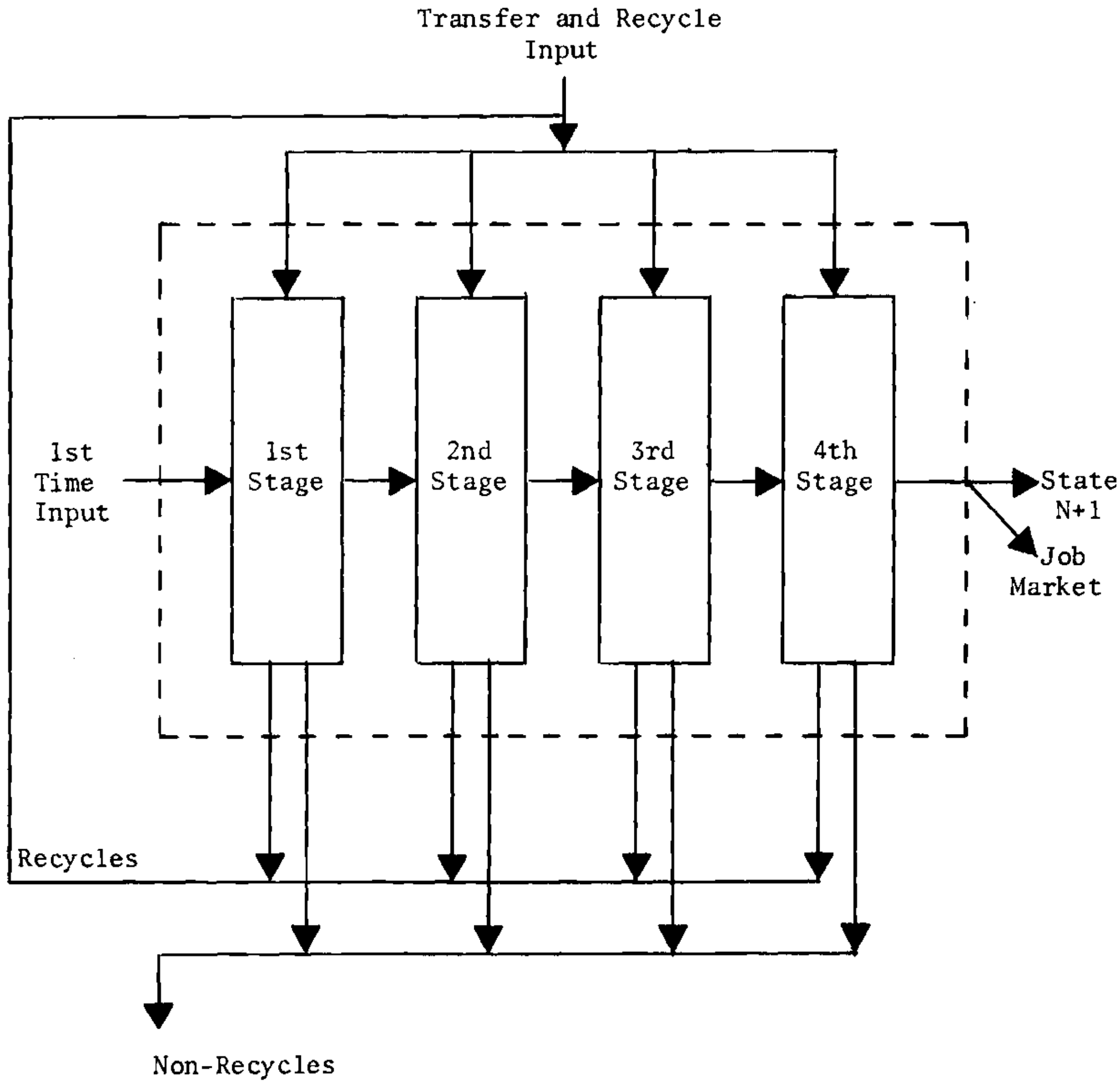


Figure 6. The Transformation Subsystem of a University System

physical flow, faculty physical flow, curriculum, and interrelationships with the facilities, organizational, value, and time subsystems. The output phase considered the final portion of the student and faculty physical flows, and interrelationships with the value and time subsystems. A system flow model and its components were described applying the input-transformation-output technique.

Each stage in Figure 6 was partitioned into four states assuming a ten-week quarter system. One can form a mental image of a stage as a micro model to the one represented in Figure 6. It was more feasible to design the transformation process by focusing deeper to a sublevel of a stage, which was a state. The macro system model in Figure 6 was defined as multiple stages, and a stage was defined as multiple states.

The next step in this design was to model the transformation subsystem using the reference frame of a state. Several subsystems and components were defined as part of the input-transformation-output relationship within a state. The student physical flow was the most important component in all three phases. Figure 7 shows a flow model of this component, and each block of the model belonged to one of the three phases. For example, blocks SP1, SP2, SP3, SP4, SP5, SP6, and SP7 belonged to the input phase. The output flows of blocks--SP5, SP6, and SP7--were defined as input flows to the transformation phase: SP8, SP9, and SP10. Figure 7 describes the output phase of the student physical flow model.

Another flow component, faculty physical flow, was an important

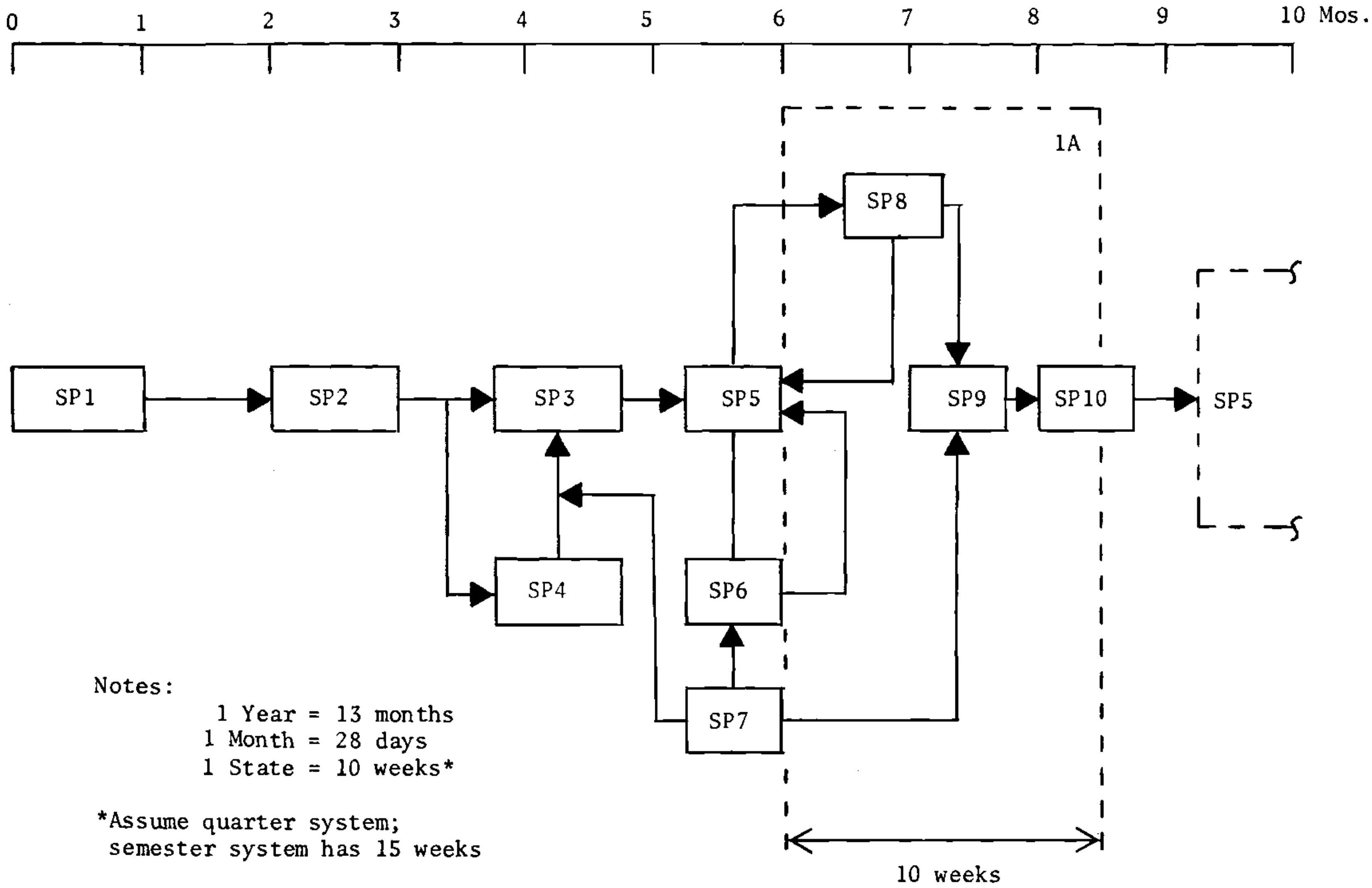


Figure 7. Student Physical Flow Model

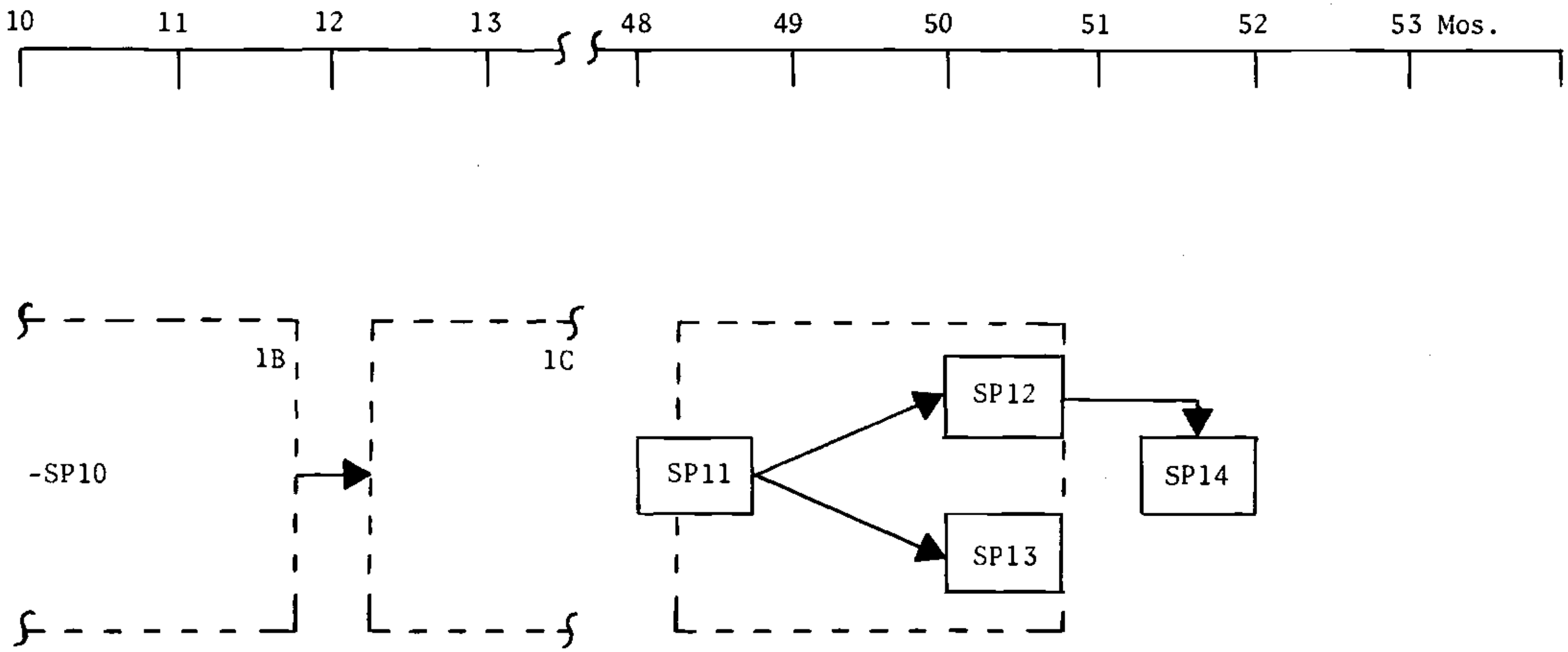


Figure 7. Continued

EXPLANATORY NOTES:

SP1 = Student application for admission

SP2 = Letter of acceptance from university system

SP3 = Preregistration work sheet

SP4 = Psychological and sociological tests for first-time student

SP5 = Registrar record I or registration of classes

SP6 = Student fees

SP7 = University system catalog

SP8 = Drop slip for dropped course

SP9 = Preregistration work sheet

SP10 = Registrar record II or grade report

SP11 = Registrar record III or graduation list

SP12 = Graduation diploma

SP13 = Alumni association record

SP14 = Registrar record IV or transcript of grades

Figure 7. Concluded

part of the transformation phase. A model representing this flow is shown in Figure 8. This design regarded the faculty flow model as part of the transformation phase in the transformation subsystem. Recall that the faculty were excluded from the people component of the transformation process.

The third component to the transformation phase was curriculum. Curriculum was defined as the outline of courses required for the certification of a student by the system. It was the proposed sequence of processing which students followed to certify that State B was greater than State A in the transformation subsystem. The curriculum was a crucial criterion to certifying the product for use in another system.

Three new components--students, faculty, and curriculum--were introduced in the transformation subsystem. Two existing subsystems--facilities and organization--overlay the transformation subsystem causing interrelationships which were vital in developing criteria. Value and time also overlay the transformation subsystem. All seven components were parts of the transformation subsystem, and they interacted with the subsystem at different phases:

INPUT PHASE--student physical flow, value, and time overlay.

TRANSFORMATION PHASE--student physical flow, faculty physical flow, facilities, organization, curriculum, value, and time overlay.

OUTPUT PHASE--student physical flow, value, and time overlay.

This design of the transformation subsystem was followed through in the simulation model. Each phase of the transformation subsystem had variables representing it. Through this representation the student

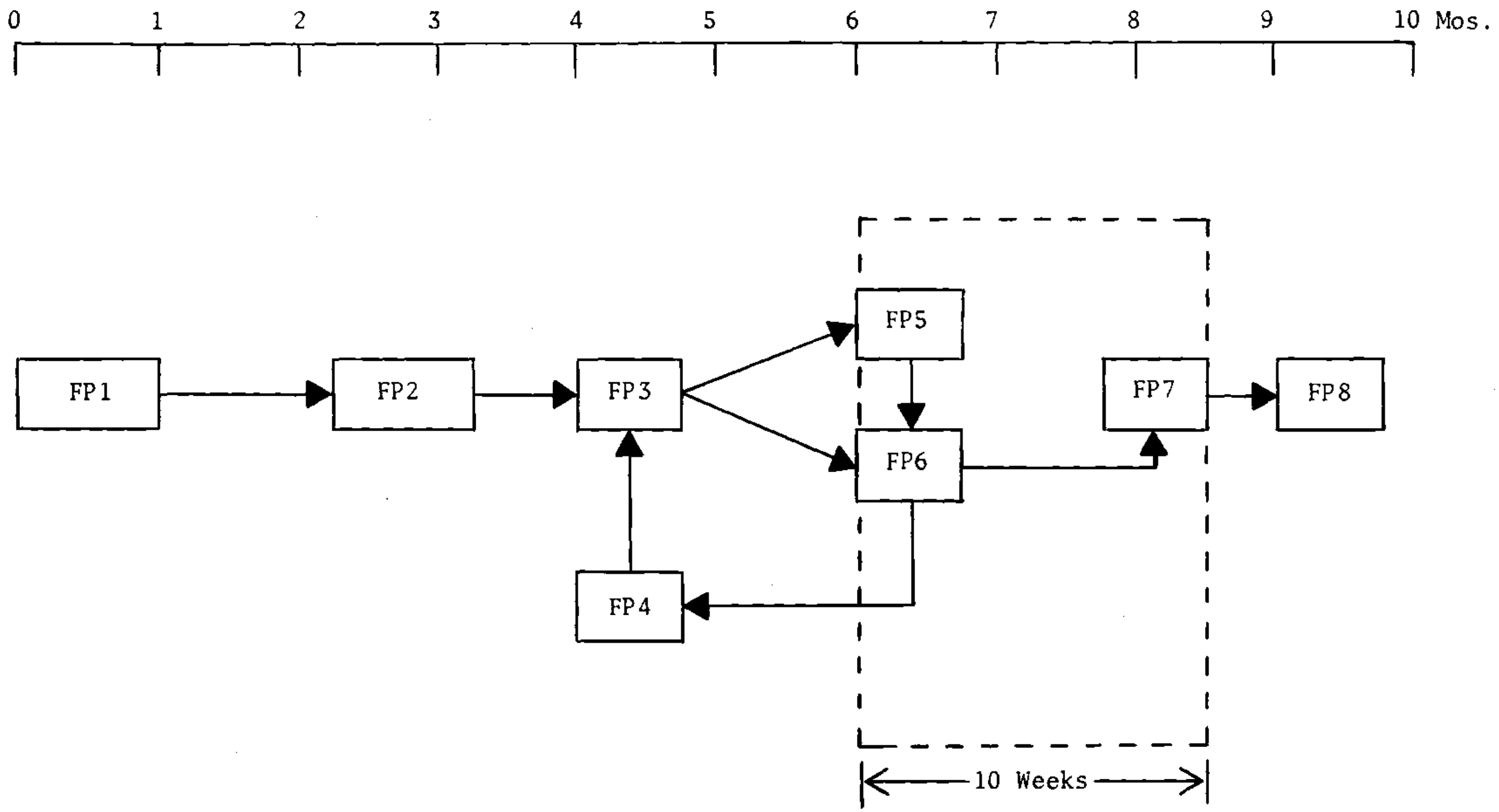


Figure 8. Faculty Physical Flow Model

EXPLANATORY NOTES:

FP1 = Application for job

FP2 = Acceptance letter to prospective faculty

FP3 = Contract agreement with university system

FP4 = Evaluation of contract agreement

FP5 = Registrar record I or class rosters

FP6 = Work hours for research, teaching and advising, professional development, and community service

FP7 = Grades recorded by faculty

FP8 = Registrar record II or grade sheets from faculty

Figure 8. Concluded

was transformed from State A to State B, such that State B was greater than State A.

A state was the reference frame used to design a model of the transformation subsystem. Four states constituted one stage of the macro system. The design was flexible so that more than one time period could be used in the model. For this design a ten-week time period was assumed.

Knowledge

Knowledge overlays the transformation subsystem and attached to the student flowing through the process. Content knowledge was an attribute of a student who was processed in the university system. In this design, knowledge content output was a credit hour which was listed on the permanent record of a student. Also on the permanent record was one's grade average, which reflected process knowledge. A student acquired credit hours through the learning system by transforming knowledge content in the classroom. These credit hours attached to the student and remained for a period of time specified by the university system. This design restricted knowledge to a precise definition of process and content for modeling purposes.

It was assumed subjects or courses could be specified by a certain number of principles. A principle was defined as a main topic of the subject which constituted content knowledge. It accomplished the first step in measurement. A subject or course was designed according to the number of principles specified in its content. After a student acquired one principle through the knowledge process, this model accumulated a knowledge unit as one principle multiplied by the

the grade. Therefore, the amount of knowledge accumulated by the student depended upon two variables: the grades received or process knowledge and the number of principles received or knowledge content.

As stated earlier, subjects or courses were constructed of principles or knowledge content; therefore, the principle variable was one important part of the design. The other part was the number of principles processed, or knowledge processed by the student. Besides the principle and grade variables, others were the number of students in each department, the number of credit hours registered per student, the number of classes taught weekly by the faculty member, and the number of faculty members in each department. All these variables were contained in the transformation subsystem; subsequently, the interaction with the knowledge subsystem was demonstrated. The process and content variables of the knowledge subsystem were the two most important parts of this model.

Knowledge value was measured by estimating the number of credit hours involved in specifying the principles of a course. Additional hours were accumulated from the time to write-up the principles to their processing time. This measure of knowledge value was adequate for this system design. It demonstrated that the value of knowledge could be measured based on the money criterion. Other variables were involved but they required further research and transformation into a known state.

This model outputted process and content knowledge in terms of grade average and credit hours which attached to the student flowing through the system. Knowledge was defined as the acquisition of a principle through the learning system. Principles specified the content of the subjects or courses in the subsystem. The knowledge subsystem was modeled as an overlay to the transformation subsystem, thereby demonstrating their strong interaction.

Communication

The communication subsystem overlays the other subsystems: facilities, organization, transformation, and knowledge. Communication was a critical linkage in systems design between the power subsystem and the physical subsystem. Also it was the medium for transfering knowledge from its abstract stages to the student's learning mechanisms. One can see the important role that communication played in the university system.

In the communication subsystem, approximately nine elements were designed into the system model: communication device, communication network nodes, communication nodes, efficiency of communication, timing and timeliness of communication, feedback, noise in the communication subsystem, and communication value (65). Five communication devices were defined as verbal, computer, written, telephone, and all other types. A communication-network node or C-N node was defined as a date in which communication was scheduled to occur (reference is the school calendar). Communication nodes were places where communication arrives and leaves; however, the same amount of communication does not necessarily leave as may arrive. A good example was an electrical circuit node where current flows in and out. The classroom, where each student was a node linked to the teacher, was a practical example in the university system. Efficiency of communication was defined on a 100 percent base with the transmission of an exact message, then reception could be more or less than 100 percent. Timing of communication was concerned with the state of readiness of the sender and receiver and synchronization between them. Timeliness of communication was concerned with the sender and receiver and their combined relationship to the message. Feedback was defined as the mirror image of the original sending and receiving sequence; noise was defined as purely negative, working in direct opposition to the message. Communication value was based on a successful communication or the failure to communicate. Whether the communication was a success or failure, each element of the communication subsystem was given a value based on the money criterion. Nine elements of the communication subsystem were defined and constructed into the system design.

Another characteristic of the design was the communication flow. Communication was a shadow of the student physical flow; that is, wherever a student flowed in the system the communication subsystem tracked him. Also the shadow concept applied to the faculty physical flow through the university system. The shadow concept clarified the abstractness of communication because it was related to the physical flow models in the transformation subsystem. However, the variables representing the elements in the communication model were different from the variables in the transformation flow models.

The nine variables defined earlier were designed into each block of the student and faculty flow models. An examination communication block was inserted into the student and faculty flow models. One other subsystem considered in the communication subsystem design was organization. Each level of the organization was represented by the nine variables mentioned above. With the addition of the organizational subsystem, the initial communication subsystem design was balanced. The design resembled the university system in enough completeness so that one could view the communication overlay of the total system.

Communication was considered a critical link in the design circle. The model variables adequately represented the subsystem which allowed the completion of an initial design of a university system.

Value

Value was the common integrator of all the subsystems. It was a first-order subsystem that overlays the whole university system, providing a common linkage to all the subsystems. The design was a collection of all the value subsets in the other subsystems to form one set. Another characteristic of this design was the value profile of the university system which was a summation of all the value criteria into a few selected ones. This design illustrated the common link of all the university subsystems.

Money was introduced as a criterion to determine the importance between one or more components of the university system. This criterion permitted one to place a dollar worth between one or more objects or events and to mathematically manipulate variables with complex value sets.

Measuring variables based on the money criterion was a primary objective of this research. The system was well constructed of value related variables; therefore, a concentrated effort in measuring these variables was forthcoming. The value subsystem, which provided a powerful evaluation of the university system, was a collection of the value subsets from each subsystem. Other criteria could be developed; however, value based on the money criterion demonstrated sufficiently the value subsystem of the university system.

In the facilities subsystem, the appreciation and depreciation models were incorporated into the model. Buildings and equipment, with the exception of land and people, depreciated over the passage of time. Land is presently an appreciating asset and it was treated as such in the model. The straightline depreciation model was applied with the assumption of a zero salvage value at the end of fifty years for a building and ten years for a unit of equipment. People generally appreciate in value up to a certain point in time and then they depreciate. At the present time the model treats the value of people as an appreciating asset.

The value model divided up the system into value centers (positive and negative) by grids. This design concept enhanced the model because a gross measure quickly revealed value densities for the whole system. Cost centers or benefit centers were established which provided powerful evaluation procedure.

The single-payment financial model with interest compounded annually was designed in the value subsystem. This financial model was heavily utilized in the real system and had been validated by volumes of past historical records. Another financial model, the uniform gradient-series, was designed into the value subsystem to measure the system's product value. The product value was measured based on an average market value for a student with a bachelor's degree and a forty-year work time period. Two financial models were designed into the value subsystem.

Single-Payment Compound-Amount Factor (66)

$$F = P(1 + i)^n , \tag{1}$$

where i = the annual interest rate

n = the number of annual interest periods

P = a present principal sum

F = a future sum, in annual interest periods, hence, equal to the compound amount of a present principal sum P

Uniform Gradient-Series Factor (67)

$$A = A_1 - g\left\{\frac{1}{i} - \frac{n}{i}\left(\frac{i}{(1+i)^n - 1}\right)\right\} \tag{1.1}$$

where i = the annual interest rate

A_1 = payment at the end of first year

g = annual change or gradient

n = the number of years

A = the equivalent equal annual payment

Organizational, transformation, knowledge, and communication subsystems remained the same design in the value model as in their original models. The detail breakdowns, which existed in their original models, were replaced by summing criteria. For example, the transformation subsystem was represented by processing input value, value of dropped courses, value of absenteeism, and product value. These four measures in this model closely represented the value overlay of the original transformation subsystem. This strategy was applied to the other three subsystems.

An additional enhancement to the value model was the profile of the whole university system. By summing all the subsystem values, an estimated system value was calculated for each grid. Another calculation was an estimate of the daily value for the whole university system. The final criterion was the difference between input and output value for the whole university system. The importance of the value subsystem was established through a description of several measures in this model.

Time

The time subsystem overlays the whole system as does value. Time was also a multi-meaning word which was partially developed into a very useful criterion. Broken into subsets, time could be defined as chronological, irretrievable, time series, exponential smoothing, networks, and markovian (68). These defined subsets of time could overlay the university system.

Chronological time was the most widely used subset of time in the whole model. The other subsets of time could be developed in the models but not in criteria. Irretrievability was applied to a degree because the model was designed to move forward in time and not backwards. Also time was critical in the data collection step because all the data had to be collected from the same chronological time period.

A few assumptions in the time overlay of the transformation subsystem were made. One year was broken into thirteen months for sake of design, fifty-two weeks in a year, or four weeks per month. Figures 7 and 8 of the transformation subsystem section represent time as assumed in the preceding sentence. Further assumptions were that ten weeks made up a state, four states represented one school year based on a quarter system, twelve states constituted a bachelor's degree, sixteen states a master's degree, and twenty-four states a doctorate.

Time was another common link to all the subsystems. Therefore, it was a critical first-order subsystem in the total system model. Chronological time was designed in all the subsystems along with the irretrievability of time. The other subsets of time--time series, exponential smoothing, networks, and markovian--influenced the model designing, but do not directly affect the development of any criteria.

Dynamics

Dynamics overlays the static subsystem models and caused change in the variables over time. Dynamics relied on the static concepts only as a means to temporarily stop and study the system or make changes to it. All the subsystems designed were static models until dynamics was implemented, then they changed through time. Because all the models were initially in a static state, evaluating a dynamic system simply meant to evaluate the whole system on time increments in the static state. The whole system was stopped at defined increments, evaluated, again moved through time, stopped, and evaluated, etc. Connecting the points of each increment over a specified passage of time represented the dynamic system. The dynamic subsystem relied on the static concepts of the system to temporarily stop the system and evaluate it.

Dynamics was designed to change the variables of the static models through time. If one wanted to evaluate the system on a yearly time increment over a five-year period, the model stopped the system and evaluated it. Then the model moved through another increment and stopped; and evaluated again. The system was evaluated five times, and by linearly connecting each point over the five-year period the dynamics of the system were studied.

The Static Subsystems

To authenticate the system model it was essential to include all the necessary subsystems. The following section discusses those subsystems that were chosen to remain static rather than dynamic. It was beyond the reasonable realm of this research to design these subsystems and simulate them. However, the chance for an invalid model was recognized, since the degree of refinement for the model was low. The model was assumed invalid if any of these static subsystems change.

Legal

An important subsystem in the university system was the legal set. The legalistic aspect of the system was primarily a set of constraints imposed on the system by the societal systems. An unique set of laws were customized to satisfy the nature of the administrative function of the system. It was an assumption that this model behaved within the present legal system constraints. Consequently, the model did not consider changes in any part of the legal system, unless a change occurred in the legal system that would invalidate the model.

Moral and Ethical

These two subsystems were distinctive but not mutually exclusive sets in the university system. It was not intended to elaborate on the moral and ethical set in this research. In passing over, however, they were associated with the philosophical set. Criteria of this set might be developed from the honesty or dishonesty characteristics inherent in the university system. This model was not intended to include the moral and ethical subsystem but to mention their existence.

Philosophical Subsystem

The philosophical subsystem is the basis for setting and expressing the overall primary goals of the system. It is these complex goals which directs the system through various stages of development. There were the idealized goals which gave long-range planning a purpose, and those goals which were concerned with the actual behavior and short-range comparison of the system to the idealized ones. This particular model was concerned with the standard philosophical sets of the professional engineer.

By the engineering philosophical set was meant those philosophies which contributed to innovative technological change of the system. The change is not too disruptive nor caused traditional profound patterns of behavior to be replaced with less desirable schemes. Also the opposite change is not intended; change that is slow or change that produces slow growth. The engineering philosophy recognizes the contributions of technological change; therefore, it is obligated to continue and direct new and tested innovations in an orderly manner (69).

Power

Power is a complex multi-dimensional subsystem which energized and de-energized the system. A reasonable attempt to model the power function was beyond the scope of this study. However, a subset of it was designed in the organizational model. This subset represented the network which channeled the power through, above, and below peer groups. Based on the market value criterion, the organizational configuration was designed using the theory of equality-inequality. The organizational subsystem was a subsubsystem of the power function which provided a reasonable alternative to the power subsystem design.

Technology

The technology subsystem was a first-order subsystem, assumed to remain unchanged in the university system. One could not avoid mentioning this subsystem because significant technological advances have occurred in university systems. Moreover, science and engineering were called upon to secure order in the systems development. The most important changes were the computer and its software which integrated change in the system. The technological subsystem was statically defined to assure the completeness of the university system model.

Summary

Eight models were designed representing the structure of the university system. The facilities subsystem was separated into land, buildings, equipment, and people components. A grid model was designed to represent the land component, and the other three components interacted with the model. The organizational hierarchical structure was modeled applying the three-dimensional mathematical model. Transformation subsystem was modeled using a state as the microscopic reference frame designed around student and faculty flow models. Knowledge was modeled using both process and content variables. The shadow concept was applied in designing the communication model around the three major components of student flow, faculty flow, and the organization. The value model was designed using the fundamental models of appreciation and depreciation, single-payment annual-compound series, and the uniform gradient-series. Chronological time overlays the entire system, and dynamics were modeled to change the system variables over time. An initial attempt toward modeling the total university was accomplished through these eight active designs.

The university system was designed into fourteen first-order internal subsystems. To focus this research the university was abstractly encircled for study. Eight of the subsystems were actively designed, as described briefly in the previous paragraph. Six subsystems--legal, moral and ethical, philosophical, power, and technology--were designed as constant.

Development of Quantitative Criteria

Quantitative criteria were developed for each subsystem from the application of measurement theory and value theory. Each subset of the university system was assigned a set of quantitative criteria. All the sets of criteria, when combined, constituted the evaluation of a university system.

The development of these quantitative criteria is presented in Appendix B.

CHAPTER IV

SYSTEM SIMULATION MODEL

A simulation model was designed to experiment with the university model. Simulating the university model made it possible to manipulate and study the internal operations of the system. The mathematical expressions in the simulation are presented in the following section, and the flow diagrams of the system simulation are shown in skeletal form. Also a sample of the simulation results is summarized.

General Description

In this simulation model a general approach was outlined which applied to all the subsystem models. The only differences in the models were their degree of complexity and a larger number of interrelationships among the variables as more levels of the university were simulated. Their similarities were the mathematical relationships which were deterministic and represented by first- and second-order equations; data, which were collected before the simulation run, were inputted by a two-dimensional array or matrix; the simulation model interacted with the user; the main thrust of each model was manipulating the variables so that the output contained the criteria; the models linked sequentially and passed variables to demonstrate the interactive nature of the university system. Each simulation model could run as a separate module from the others. BASIC was the programming language and the UNIVAC 1108 was the computer system (73).

These simulation models followed the strategy of systematic construction. Selected mathematical equations were extracted from the simulation programs. These equations were the mathematical models which represented the university system behavior. Every model's logical structure was charted using flow diagrams.

In the following section an example of the mathematical equations and logical operation is presented. Appendix C contains the remaining simulation models.

Facility Model--Land

Mathematical Relationships

These mathematical expressions simulated the behavior of the land component of the university system. Data were manipulated by the equations to produce the criteria for the evaluation of the land component. These data were collected prior to running the simulation model and were transformed into an array for the input operation. If representable data for an element of the array were not obtainable, then a zero was inserted in that position. It was required to collect the data for each grid from the same chronological time period. This satisfied the requirement of the time overlay of the university system.

Dimensions for the data array were defined by R and C.

R = Total number of grids 1,2,...,r of the land component

C = 13 column data vector

C1 = Grid number; identified the data vector for each grid r

C2 = Number of university acres in grid

C3 = Number of acres of L1

C4 = Number of acres of L2

C5 = Number of acres of L3

C6 = Number of acres of L4

C7 = Number of acres of L5

C8 = Slope or grade of land in grid (see Appendix A)

C9 = Number of acres of L6

C10 = Number of acres of L7

C11 = Number of acres separated from central campus

C12 = X coordinate of grid

C13 = Y coordinate of grid

The data elements were manipulated by the following mathematical expressions in the simulation program. These equations were a subset of the equation set in the program.

1. Sum the column vectors: C2, C3, C4, C5, C6, C7, C9, C10, C11.

$$\sum_{I=1}^{r} (L,L1,L2,L3,L4,L5,L6,L7,L8)_I , \tag{2}$$

where I = 1,...,r grids in the university system.

2. The average slope of the land was

$$\sum_{I=1}^{r} L16/r \ . \tag{3}$$

3. The percentage of nonvacant land to the total university land was given by

$$\sum_{I=1}^{r} (L6)_I \Bigg/ \sum_{I=1}^{r} L_I \ , \tag{4}$$

and the percentage of vacant land to the total university land was

$$\sum_{I=1}^{r}(L7)_I \Big/ \sum_{I=1}^{r} L_I \ . \tag{4.1}$$

4. Degree of contiguity could be measured using a ratio equation which gave

$$\sum_{I=1}^{r}(L8)_I \Big/ \sum_{I=1}^{r} L_I \ . \tag{5}$$

5. To calculate the distance between two grids, $r_A(L11,L12)$ and $r_B(L11,L12)$, the centroid had to be calculated for the central campus. By defining the number of grids in the central campus on the X-axis and the number of grids in the central campus on the Y-axis, the coordinates of the central grid were calculated as (L9/2, L10/2). Applying the distance formula for two points on a plane, the distance between each grid was

$$\left[(L9/2 - L11)^2 + (L10/2 - L12)^2\right]^{\frac{1}{2}} . \tag{6}$$

6. Given the distance between the grids and the central grid from (6), the degree of compactness was given by

$$\sum_{I=1}^{r}\left[(L9/2 - L11)^2 + (L10/2 - L12)^2\right]_I^{\frac{1}{2}}/r \ . \tag{7}$$

7. Another data vector [L13,L14,L15] was inputted containing the market value elements corresponding to each location variable.

Using a double summation equation and letting X(J) = [L13,L14,L15] where J = 3, 4, 5, A(I,J) equal the elements in the R × C data array corresponding to the location variables L1, L2, and L3. The location variables were elements A(I,3), A(I,4), and A(I,5) respectively in the R × C data array. The market value vector for each grid r was calculated from

$$\sum_{I=1}^{r} \sum_{J=3}^{5} A(I,J)*X(J) \quad . \tag{8}$$

These mathematical expressions represented the land component in the simulation model. Generally, the equations were not elaborately developed, but they were systematically applied to evaluate the land component of the university system. More mathematical relationships are shown in the operational logic of the simulation model.

Operational Logic

This section presents the logical flow of the simulation programs. It was not possible to diagram every program statement, but a skeletal flow of every mathematical expression is shown. All the mathematical relationships related to the simulation model were part of the operational logic. The logical flow of the simulation model in Figure 9 shows the mathematical relationships representing the land component.

Four parameters were passed from this logic: the total university acreage, the total market value of university land, and the X and Y coordinates of the central grid.

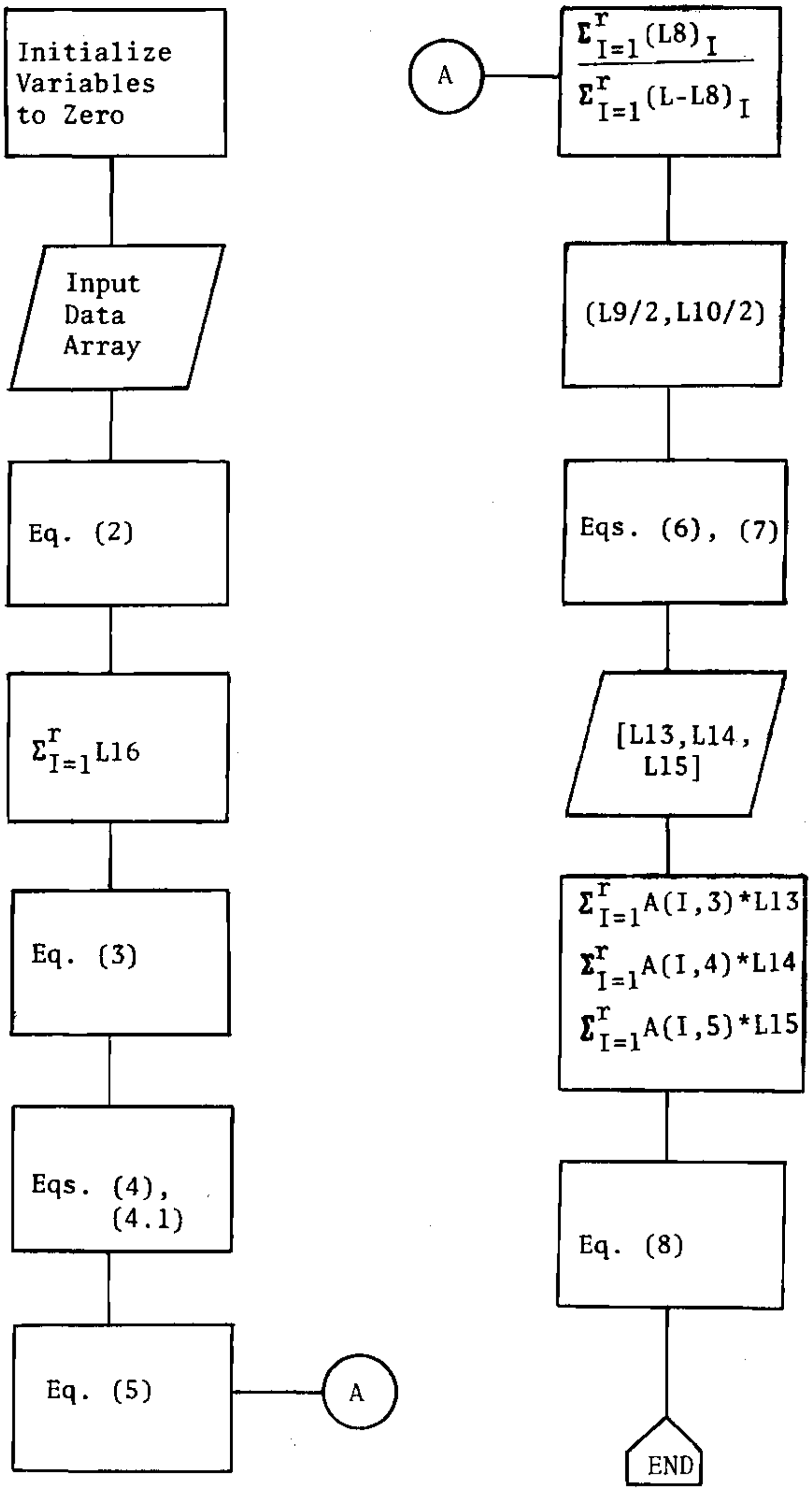


Figure 9. Facility Model--Land Component Logic Diagram

Summary of Simulation Results--A Sample

This section gives an example of the simulation model input and output. Several thousand input data were processed, and over a thousand pages of output from the simulation model were produced. These volumes of input and output data make it impractical to display all the details for the reader. Consequently, the input data and output results of the land simulation model are presented to give a sample of the actual results.

Figure 10 is a specimen of the interaction which took place at a remote terminal for a two-year simulation run. An @ADD statement adds the input data for each data array to the job stream of the simulation run. The constant, .1, is the preselected growth multiplier which is the system's dynamics of the university model. This constant was taken from a table of 10 percent interest factors for annual compounding interest for one year (74). The growth factors for a five-, ten-, and twenty-five-year simulation run were .611, 1.6, and 9.84.

Input data were transformed into the data array defined in the section under mathematical relationships of the facility model--land. Table 4 shows these data for 166 grids of the pilot university.

Table 5 shows the output results for the second year of a two-year simulation run. The output results for everything but land market value were identical to the first year results because the land component was simulated to remain constant. Land market value was simulated to grow 10 percent in the second year.

The total number of acres defined as the central campus were 85.87999 acres. Adding the number of acres separated from main or

```
>>@BRK,F

END    UBASIC 21:05:51    23 JUL 75
OUTPUT DIVERTED TO FILE PRINTO
>@UBASIC ELMODEL2
>OLD:HA@SOO
>RUN
>1
>2
>@ADD ELMODEL2.DATA1
>.1
>@ADD ELMODEL2.DATA2
>.1
>@ADD ELMODEL2.DATA3
>.1
>@ADD ELMODEL2.DATA4
>.1
>@ADD ELMODEL2.DATA5
>.1
>@ADD ELMODEL2.DATA6P1
>.1
>@ADD ELMODEL2.DATA6P2
>.1
>@ADD ELMODEL2.DATA6P3
>.1
>@ADD ELMODEL2.DATA6P4
>.1
>@ADD ELMODEL2.DATA7
>.1
>@ADD ELMODEL2.DATA8
>.1
>@ADD ELMODEL2.DATA9
>.1
>.1
>.1
>.1
>.1
>.1
>.1
>.1
>.1
>.1
>.1
>.1
>.1
>STOP
>@BRK,TY
```

Figure 10. Specimen of the Interaction on a Remote Terminal for a Two-Year Simulation Run

Table 4. Input Data for Land Component Simulation Model

1	0	.45	0	0	.45	0	.8	.1	.35	.45	.5	.5
2	.48	.48	0	0	.48	0	.8	.1	.38	0	1.5	.5
3	.5	.5	0	0	.5	0	.8	.25	.25	0	2.5	.5
4	.6	.6	0	0	.6	0	.75	.1	.5	0	3.5	.5
5	.55	.55	0	0	.55	0	.67	.55	0	0	4.5	.5
6	0	0	0	0	0	0	.8	0	0	0	5.5	.5
7	0	0	0	0	0	0	.8	0	0	0	6.5	.5
8	0	.1	0	0	.1	0	.64	0	.1	.1	7.5	.5
9	0	.4	0	0	.4	0	.57	0	.4	.4	8.5	.5
10	0	.8	0	0	.8	0	.62	0	.8	.8	9.5	.5
11	0	.75	0	0	.75	0	.72	0	.75	.75	10.5	.5
12	0	.3	0	0	.3	0	.9	0	.3	.3	11.5	.5
13	0	.4	0	0	.4	0	.9	0	.4	.4	12.5	.5
14	0	0	0	0	0	0	0	0	0	0	13.5	.5
15	0	0	1	0	1	0	.8	.4	.6	1	.5	1.5
16	1	1	0	0	.8	.2	.8	.5	.5	0	1.5	1.5
17	1	1	0	0	.7	.3	.57	1	0	0	2.5	1.5
18	1	1	0	0	1	0	.64	1	0	0	3.5	1.5
19	1	1	0	0	1	0	.69	1	0	0	4.5	1.5
20	.6	.6	0	0	.6	0	.69	.6	0	0	5.5	1.5
21	.05	.45	0	0	.45	0	.67	0	.45	.4	6.5	1.5
22	0	.95	0	0	.95	0	.46	0	.95	.95	7.5	1.5
23	0	1	0	0	1	0	.52	0	1	1	8.5	1.5
24	0	1	0	0	1	0	.72	0	1	1	9.5	1.5
25	0	1	0	0	1	0	.87	0	1	1	10.5	1.5
26	0	1	0	0	1	0	.97	0	1	1	11.5	1.5
27	0	1	0	0	1	0	1	0	1	1	12.5	1.5
28	0	.75	0	0	.75	0	.87	0	.75	.75	13.5	1.5
29	0	1	0	0	1	0	.8	.1	.9	1	.5	2.5
30	1	1	0	0	.5	.5	.57	.5	.5	0	1.5	2.5
31	1	1	0	0	1	0	.57	1	0	0	2.5	2.5
32	1	1	0	0	.9	.1	.6	1	0	0	3.5	2.5
33	1	1	0	0	1	0	.63	.6	.4	0	4.5	2.5
34	1	1	0	0	.4	.6	.55	1	0	0	5.5	2.5
35	.75	.75	0	0	.75	0	.62	.5	.25	0	6.5	2.5
36	.2	.6	0	0	.6	0	.45	0	.6	.4	7.5	2.5
37	0	.85	0	0	.85	0	.53	0	.85	.65	8.5	2.5
38	0	0	.95	0	.95	0	.76	.1	.85	.95	9.5	2.5
39	0	1	0	0	1	0	.74	.6	.4	1	10.5	2.5
40	0	.75	0	0	.75	0	.82	0	.75	.75	11.5	2.5
41	0	0	.5	0	.5	0	.97	0	.5	.5	12.5	2.5
42	0	.3	0	0	.3	0	.85	0	.3	.3	13.5	2.5
43	0	0	1	0	.6	.4	.8	.5	.5	1	.5	3.5
44	1	1	0	0	.6	.4	.57	.6	.4	0	1.5	3.5
45	1	1	0	0	1	0	.57	1	0	0	2.5	3.5
46	1	1	0	0	.2	.8	.55	.3	.7	0	3.5	3.5
47	1	1	0	0	.8	.2	.54	.1	.9	0	4.5	3.5
48	1	1	0	0	0	1	.54	.1	.9	0	5.5	3.5
49	1	1	0	0	1	0	.57	.4	.6	0	6.5	3.5
50	.25	.25	0	0	.25	0	.5	0	.25	0	7.5	3.5
51	0	.15	0	0	.15	0	.68	0	.15	.15	10.5	3.5

Table 4. Continued

52	0	.2	0	0	0	.2	.76	0	.2	.2	11.5	3.5
53	0	.1	0	0	0	.1	.9	0	.1	.1	12.5	3.5
54	0	.3	0	0	.3	0	.76	0	.3	.3	13.5	3.5
55	.7	0	1	0	.5	.5	.8	.6	.4	.3	.5	4.5
56	1	1	0	0	.4	.6	.57	.25	.75	0	1.5	4.5
57	1	1	0	0	1	0	.57	.5	.5	0	2.5	4.5
58	1	1	0	0	.4	.6	.3	1	0	0	3.5	4.5
59	1	1	0	0	.1	.9	.5	.1	.9	0	4.5	4.5
60	1	1	0	0	1	0	.3	1	0	0	5.5	4.5
61	.9	.9	0	0	0	.9	.27	.3	.6	0	6.5	4.5
62	0	.1	0	0	.1	0	.57	0	.1	.1	9.5	4.5
63	0	.15	0	0	.15	0	.72	0	.15	.15	10.5	4.5
64	0	.4	0	0	.2	.2	.8	0	.4	.4	11.5	4.5
65	0	.1	0	0	.1	0	.78	0	.1	.1	12.5	4.5
66	0	.1	0	0	.1	0	.66	0	.1	.1	13.5	4.5
67	1	0	1	0	.5	.5	.8	.5	.5	0	.5	5.5
68	1	1	0	0	.5	.5	.23	0	1	0	1.5	5.5
69	1	1	0	0	.5	.5	.23	0	1	0	2.5	5.5
70	1	1	0	0	.4	.6	.34	.6	.4	0	3.5	5.5
71	1	1	0	0	.2	.8	.34	.75	.25	0	4.5	5.5
72	1	1	0	0	0	1	.17	0	1	0	5.5	5.5
73	.9	.9	0	0	0	1	.17	.1	.8	0	6.5	5.5
74	0	.2	0	0	.2	0	.38	0	.2	.2	8.5	5.5
75	0	.95	0	0	.95	0	.38	0	.95	.95	9.5	5.5
76	0	1	0	0	1	0	.68	0	1	1	10.5	5.5
77	0	.85	0	0	.4	.45	.57	0	.85	.85	11.5	5.5
78	0	.55	0	0	.2	.35	.65	0	.55	.55	12.5	5.5
79	1	0	1	0	.5	.5	.8	.25	.75	0	.5	6.5
80	1	1	0	0	.8	.2	.23	0	1	0	1.5	6.5
81	1	1	0	0	.8	.2	.11	0	1	0	2.5	6.5
82	1	1	0	0	.4	.6	.11	.2	.8	0	3.5	6.5
83	1	1	0	0	0	1	.11	.2	.8	0	4.5	6.5
84	1	1	0	0	.4	.6	.11	.6	.4	0	5.5	6.5
85	1	1	0	0	1	0	.23	1	0	0	6.5	6.5
86	.45	.9	0	0	1	0	.34	.1	.8	.45	7.5	6.5
87	0	1	0	0	1	0	.28	0	1	1	8.5	6.5
88	0	1	0	0	1	0	.28	0	1	1	9.5	6.5
89	0	1	0	0	1	0	.45	0	1	1	10.5	6.5
90	0	1	0	0	1	0	.45	0	1	1	11.5	6.5
91	0	.6	0	0	.6	0	.57	0	.6	.6	12.5	6.5
92	1	0	1	0	.5	.5	.11	0	1	0	.5	7.5
93	1	1	0	0	1	0	0	0	1	0	1.5	7.5
94	1	1	0	0	1	0	0	0	1	0	2.5	7.5
95	1	1	0	0	.5	.5	.04	0	1	0	3.5	7.5
96	1	1	0	0	0	1	0	0	1	0	4.5	7.5
97	1	1	0	0	0	1	.11	.2	.8	0	5.5	7.5
98	1	1	0	0	.6	.4	.11	.5	.5	0	6.5	7.5
99	.85	1	0	0	.5	.5	.34	.2	.8	.15	7.5	7.5
100	0	1	0	0	1	0	.45	.2	.8	1	8.5	7.5
101	0	1	0	0	1	0	.34	0	1	1	9.5	7.5
102	0	1	0	0	1	0	.53	0	1	1	10.5	7.5
103	0	.9	0	0	.9	0	.57	0	.9	.9	11.5	7.5
104	0	.6	0	0	.6	0	.68	0	.6	.6	12.5	7.5
105	.75	0	.75	0	.5	.5	.11	0	.75	0	.5	8.5
106	1	0	1	0	.5	.5	0	0	1	0	1.5	8.5
107	1	0	1	0	.5	.5	0	0	1	0	2.5	8.5
108	1	0	1	0	.5	.5	0	0	1	0	3.5	8.5

Table 4. Continued

109	1	0	1	0	.5	.5	0	0	1	0	4.5	8.5
110	1	0	1	0	0	1	.23	.1	.9	0	5.5	8.5
111	1	0	1	0	0	1	.38	.25	.75	0	6.5	8.5
112	1	0	1	0	.2	.8	.34	.4	.6	0	7.5	8.5
113	.4	0	1	0	1	0	.5	.6	.4	.6	6.5	8.5
114	0	0	1	0	1	0	.36	0	1	1	9.5	8.5
115	0	0	1	0	.5	.5	.6	0	1	1	10.5	8.5
116	0	0	.8	0	.4	.4	.8	0	.8	.8	11.5	8.5
117	0	0	.1	0	.1	0	.77	0	.1	.1	12.5	8.5
118	.1	0	.1	0	.1	0	.33	0	.1	0	.5	9.5
119	.95	0	1	0	1	0	.11	0	.95	0	1.5	9.5
120	1	0	1	0	1	0	.21	0	1	0	2.5	9.5
121	1	0	1	0	1	0	.23	0	1	0	3.5	9.5
122	1	0	1	0	1	0	.23	0	1	0	4.5	9.5
123	1	0	1	0	.5	.5	.18	0	1	0	5.5	9.5
124	1	0	1	0	.4	.6	.47	.75	.25	0	6.5	9.5
125	1	0	1	0	1	0	.5	1	0	0	7.5	9.5
126	.85	0	1	0	.4	.6	.57	.4	.6	.15	8.5	9.5
127	0	0	1	0	.5	.5	.57	0	1	1	9.5	9.5
128	0	0	1	0	1	0	.58	0	1	1	10.5	9.5
129	0	0	.9	0	.9	0	.74	0	.9	.9	11.5	9.5
130	0	0	.05	0	.05	0	.77	0	.05	.05	12.5	9.5
131	.05	0	.05	0	.05	0	.38	0	.05	0	1.5	10.5
132	.5	0	.5	0	.5	0	.38	0	.5	0	2.5	10.5
133	.85	0	.85	0	.85	0	.34	0	.85	0	3.5	10.5
134	1	0	1	0	1	0	.46	0	1	0	4.5	10.5
135	1	0	1	0	.5	.5	.34	0	1	0	5.5	10.5
136	1	0	1	0	.5	.5	.23	0	1	0	6.5	10.5
137	1	0	1	0	.2	.8	.46	.25	.75	0	7.5	10.5
138	1	0	1	0	.5	.5	.64	.5	.5	0	8.5	10.5
139	.4	0	1	0	1	0	.67	.4	.6	.6	9.5	10.5
140	0	0	1	0	1	0	.57	0	1	1	10.5	10.5
141	0	0	.75	0	.35	.4	.68	0	.75	.75	11.5	10.5
142	.05	0	.05	0	.05	0	.5	0	.05	0	3.5	11.5
143	.4	0	.4	0	.2	.2	.57	0	.4	0	4.5	11.5
144	1	0	1	0	.5	.5	.67	0	1	0	5.5	11.5
145	1	0	1	0	.5	.5	.42	0	1	0	6.5	11.5
146	1	0	1	0	.5	.5	.64	0	1	0	7.5	11.5
147	1	0	1	0	.5	.5	.64	.2	.8	0	8.5	11.5
148	.8	0	1	0	.8	0	.78	.2	.8	.2	9.5	11.5
149	0	0	1	0	1	0	.78	0	1	1	10.5	11.5
150	0	0	.5	0	.5	0	.8	0	.5	.5	11.5	11.5
151	.25	0	.25	0	.25	0	.57	0	.25	0	4.5	12.5
152	1	0	1	0	.5	.5	.57	0	1	0	5.5	12.5
153	1	0	1	0	.6	.4	.68	0	1	0	6.5	12.5
154	1	0	1	0	1	0	.68	0	1	0	7.5	12.5
155	1	0	1	0	1	0	.8	0	1	0	8.5	12.5
156	.95	0	.95	0	.45	.5	.92	0	.95	0	.95	12.5
157	.2	0	.4	0	.2	.2	1	0	.4	.2	10.5	12.5
158	.1	0	.1	0	.1	0	.57	0	.1	0	4.5	13.5
159	.5	0	.5	0	.5	0	.63	0	.5	0	5.5	13.5
160	.85	0	.85	0	.85	0	.63	0	.85	0	6.5	13.5
161	1	0	1	0	1	0	.76	0	1	0	7.5	13.5
162	1	0	1	0	.5	.5	.9	0	1	0	8.5	13.5
163	.3	0	.3	0	.15	.15	1	0	.3	0	9.5	13.5
164	.05	0	.05	0	.05	0	.74	0	.05	0	6.5	14.5
165	.4	0	.4	0	.2	.2	.74	0	.4	0	7.5	14.5
166	.4	0	.4	0	.2	.2	.74	0	.4	0	8.5	14.5

Table 5. Computer Printout Sample of Output from Land Component Simulation Model

```
TOTAL # OF ACRES L1 = 73.529994
TOTAL # OF ACRES L2 = 56.449996
TOTAL # OF ACRES L3 = 0
TOTAL # OF ACRES    = 85.87999

# OF ACRES L4 = [illegible]3.079981
# OF ACRES L5 = 37.149997

GRID - 1 SLOPE = .8
GRID - 2 SLOPE = .8
GRID - 3 SLOPE = .8
GRID - 4 SLOPE = .75
GRID - 5 SLOPE = .67
GRID - 6 SLOPE = .8
GRID - 7 SLOPE = .8
GRID - 8 SLOPE = .64
GRID - 9 SLOPE = .57
GRID - 10 SLOPE = .62
GRID - 11 SLOPE = .72
GRID - 12 SLOPE = .9
GRID - 13 SLOPE = .9
GRID - 14 SLOPE = 0
GRID - 15 SLOPE = .8
GRID - 16 SLOPE = .8
GRID - 17 SLOPE = .57
GRID - 18 SLOPE = .64
GRID - 19 SLOPE = .69
GRID - 20 SLOPE = .69
GRID - 21 SLOPE = .67
GRID - 22 SLOPE = .46
GRID - 23 SLOPE = .52
GRID - 24 SLOPE = .72
GRID - 25 SLOPE = .87
GRID - 26 SLOPE = .97
GRID - 27 SLOPE = 1
GRID - 28 SLOPE = .87
GRID - 29 SLOPE = .8
GRID - 30 SLOPE = .57
GRID - 31 SLOPE = .57
GRID - 32 SLOPE = .6
GRID - 33 SLOPE = .63
GRID - 34 SLOPE = .55
GRID - 35 SLOPE = .62
GRID - 36 SLOPE = .45
GRID - 37 SLOPE = .53
GRID - 38 SLOPE = .76
GRID - 39 SLOPE = .74
GRID - 40 SLOPE = .82
GRID - 41 SLOPE = .97
GRID - 42 SLOPE = .85
GRID - 43 SLOPE = .8
GRID - 44 SLOPE = .57
GRID - 45 SLOPE = .57
GRID - 46 SLOPE = .55
GRID - 47 SLOPE = .54
GRID - 48 SLOPE = .54
GRID - 49 SLOPE = .57
GRID - 50 SLOPE = .5
GRID - 51 SLOPE = .68
GRID - 52 SLOPE = .76
GRID - 53 SLOPE = .9
GRID - 54 SLOPE = .76
GRID - 55 SLOPE = .8
GRID - 56 SLOPE = .57
GRID - 57 SLOPE = .57
GRID - 58 SLOPE = .3
GRID - 59 SLOPE = .5
GRID - 60 SLOPE = .3
GRID - 61 SLOPE = .27
GRID - 62 SLOPE = .57
GRID - 63 SLOPE = .72
GRID - 64 SLOPE = .8
GRID - 65 SLOPE = .78
GRID - 66 SLOPE = .66
GRID - 67 SLOPE = .8
GRID - 68 SLOPE = .23
GRID - 69 SLOPE = .23
GRID - 70 SLOPE = .34
GRID - 71 SLOPE = .34
GRID - 72 SLOPE = .17
GRID - 73 SLOPE = .17
GRID - 74 SLOPE = .38
GRID - 75 SLOPE = .38
GRID - 76 SLOPE = .68
GRID - 77 SLOPE = .57
GRID - 78 SLOPE = .65
GRID - 79 SLOPE = .8
GRID - 80 SLOPE = .23
GRID - 81 SLOPE = .11
GRID - 82 SLOPE = .11
GRID - 83 SLOPE = .11
GRID - 84 SLOPE = .11
GRID - 85 SLOPE = .23
GRID - 86 SLOPE = .34
GRID - 87 SLOPE = .28
GRID - 88 SLOPE = .28
GRID - 89 SLOPE = .45
GRID - 90 SLOPE = .45
GRID - 91 SLOPE = .57
GRID - 92 SLOPE = .11
GRID - 93 SLOPE = 0
GRID - 94 SLOPE = 0
GRID - 95 SLOPE = .04
GRID - 96 SLOPE = 0
GRID - 97 SLOPE = .11
GRID - 98 SLOPE = .11
GRID - 99 SLOPE = .34
GRID - 100 SLOPE = .45
GRID - 101 SLOPE = .34
GRID - 102 SLOPE = .53
GRID - 103 SLOPE = .57
GRID - 104 SLOPE = .66
GRID - 105 SLOPE = .11
GRID - 106 SLOPE = 0
GRID - 107 SLOPE = 0
GRID - 108 SLOPE = 0
GRID - 109 SLOPE = 0
GRID - 110 SLOPE = .23
GRID - 111 SLOPE = .38
GRID - 112 SLOPE = .34
GRID - 113 SLOPE = .5
```

Table 5. Continued

GRID - 114	SLOPE =	.36
GRID - 115	SLOPE =	.6
GRID - 116	SLOPE =	.8
GRID - 117	SLOPE =	.77
GRID - 118	SLOPE =	.35
GRID - 119	SLOPE =	.11
GRID - 120	SLOPE =	.21
GRID - 121	SLOPE =	.23
GRID - 122	SLOPE =	.23
GRID - 123	SLOPE =	.16
GRID - 124	SLOPE =	.47
GRID - 125	SLOPE =	.5
GRID - 126	SLOPE =	.57
GRID - 127	SLOPE =	.57
GRID - 128	SLOPE =	.56
GRID - 129	SLOPE =	.74
GRID - 130	SLOPE =	.77
GRID - 131	SLOPE =	.36
GRID - 132	SLOPE =	.36
GRID - 133	SLOPE =	.34
GRID - 134	SLOPE =	.46
GRID - 135	SLOPE =	.34
GRID - 136	SLOPE =	.23
GRID - 137	SLOPE =	.46
GRID - 138	SLOPE =	.64
GRID - 139	SLOPE =	.67
GRID - 140	SLOPE =	.57
GRID - 141	SLOPE =	.68
GRID - 142	SLOPE =	.5
GRID - 143	SLOPE =	.57
GRID - 144	SLOPE =	.67
GRID - 145	SLOPE =	.42
GRID - 146	SLOPE =	.64
GRID - 147	SLOPE =	.64
GRID - 148	SLOPE =	.76
GRID - 149	SLOPE =	.76
GRID - 150	SLOPE =	.8
GRID - 151	SLOPE =	.57
GRID - 152	SLOPE =	.57
GRID - 153	SLOPE =	.68
GRID - 154	SLOPE =	.66
GRID - 155	SLOPE =	.8
GRID - 156	SLOPE =	.92
GRID - 157	SLOPE =	1
GRID - 158	SLOPE =	.57
GRID - 159	SLOPE =	.63
GRID - 160	SLOPE =	.63
GRID - 161	SLOPE =	.76
GRID - 162	SLOPE =	.9
GRID - 163	SLOPE =	1
GRID - 164	SLOPE =	.74
GRID - 165	SLOPE =	.74
GRID - 166	SLOPE =	.74

AVERAGE GRADE OF LAND = .53512021

OF ACRES L6 = 28.199996
OF ACRES L7 = 101.72998

% N/VACANT LAND OF TOTAL LAND = .32836515

% VACANT LAND OF TOTAL LAND = 1.1845597

OF ACRES SEPARATED FROM MAIN CAMPUS = 44.049995

DEGREE OF CONTIGUITY = .51292501

% SEPARATED LAND PARCELS TO CENTRAL CAMPUS LAND PARCELS = 1.053072

CENTROID OF LAND =(5.5 , 7.5)

DISTANCE FROM CENTROID OF CAMPUS

GRID NO. 1	8.6023252
GRID NO. 2	8.0622576
GRID NO. 3	7.6157731
GRID NO. 4	7.2801099
GRID NO. 5	7.0710678
GRID NO. 6	7
GRID NO. 7	7.0710678
GRID NO. 8	7.2801099
GRID NO. 9	7.6157731
GRID NO. 10	8.0622576
GRID NO. 11	8.6023252
GRID NO. 12	9.2195444
GRID NO. 13	9.8994949
GRID NO. 14	10.630146
GRID NO. 15	7.8102496
GRID NO. 16	7.2111025
GRID NO. 17	6.708204
GRID NO. 18	6.3245553
GRID NO. 19	6.0827625
GRID NO. 20	6
GRID NO. 21	6.0827625
GRID NO. 22	6.3245553
GRID NO. 23	6.708204
GRID NO. 24	7.2111025
GRID NO. 25	7.8102496
GRID NO. 26	8.4852813
GRID NO. 27	9.2195444
GRID NO. 28	10
GRID NO. 29	7.0710678
GRID NO. 30	6.4031242

Table 5. Continued

GRID NO. 31	5.8309519	GRID NO. 88	4.1231056
GRID NO. 32	5.3851648	GRID NO. 89	5.0990195
GRID NO. 33	5.0990195	GRID NO. 90	6.0827625
GRID NO. 34	5	GRID NO. 91	7.0710678
GRID NO. 35	5.0990195	GRID NO. 92	5
GRID NO. 36	5.3851648	GRID NO. 93	4
GRID NO. 37	5.8309519	GRID NO. 94	3
GRID NO. 38	6.4031242	GRID NO. 95	2
GRID NO. 39	7.0710678	GRID NO. 96	1
GRID NO. 40	7.8102496	GRID NO. 97	0
GRID NO. 41	8.6023252	GRID NO. 98	1
GRID NO. 42	9.4339811	GRID NO. 99	2
GRID NO. 43	6.4031242	GRID NO. 100	3
GRID NO. 44	5.6568543	GRID NO. 101	4
GRID NO. 45	5	GRID NO. 102	5
GRID NO. 46	4.472136	GRID NO. 103	6
GRID NO. 47	4.1231056	GRID NO. 104	7
GRID NO. 48	4	GRID NO. 105	5.0990195
GRID NO. 49	4.1231056	GRID NO. 106	4.1231056
GRID NO. 50	4.472136	GRID NO. 107	3.1622776
GRID NO. 51	6.4031242	GRID NO. 108	2.236068
GRID NO. 52	7.2111025	GRID NO. 109	1.4142136
GRID NO. 53	8.0622576	GRID NO. 110	1
GRID NO. 54	8.9442718	GRID NO. 111	1.4142136
GRID NO. 55	5.8309519	GRID NO. 112	2.236068
GRID NO. 56	5	GRID NO. 113	3.1622776
GRID NO. 57	4.2426407	GRID NO. 114	4.1231056
GRID NO. 58	3.6055513	GRID NO. 115	5.0990195
GRID NO. 59	3.1622776	GRID NO. 116	6.0827625
GRID NO. 60	3	GRID NO. 117	7.0710678
GRID NO. 61	3.1622776	GRID NO. 118	5.3851648
GRID NO. 62	5	GRID NO. 119	4.472136
GRID NO. 63	5.8309519	GRID NO. 120	3.6055513
GRID NO. 64	6.708204	GRID NO. 121	2.8284271
GRID NO. 65	7.6157731	GRID NO. 122	2.236068
GRID NO. 66	8.5440037	GRID NO. 123	2
GRID NO. 67	5.3851648	GRID NO. 124	2.236068
GRID NO. 68	4.472136	GRID NO. 125	2.8284271
GRID NO. 69	3.6055513	GRID NO. 126	3.6055513
GRID NO. 70	2.8284271	GRID NO. 127	4.472136
GRID NO. 71	2.236068	GRID NO. 128	5.3851648
GRID NO. 72	2	GRID NO. 129	6.3245553
GRID NO. 73	2.236068	GRID NO. 130	7.2801099
GRID NO. 74	3.6055513	GRID NO. 131	5
GRID NO. 75	4.472136	GRID NO. 132	4.2426407
GRID NO. 76	5.3851648	GRID NO. 133	3.6055513
GRID NO. 77	6.3245553	GRID NO. 134	3.1622776
GRID NO. 78	7.2801099	GRID NO. 135	3
GRID NO. 79	5.0990195	GRID NO. 136	3.1622776
GRID NO. 80	4.1231056	GRID NO. 137	3.6055513
GRID NO. 81	3.1622776	GRID NO. 138	4.2426407
GRID NO. 82	2.236068	GRID NO. 139	5
GRID NO. 83	1.4142136	GRID NO. 140	5.8309519
GRID NO. 84	1	GRID NO. 141	6.708204
GRID NO. 85	1.4142136	GRID NO. 142	4.472136
GRID NO. 86	2.236068	GRID NO. 143	4.1231056
GRID NO. 87	3.1622776	GRID NO. 144	4

Table 5. Continued

GRID NO. 145	4.1231056
GRID NO. 146	4.472136
GRID NO. 147	5
GRID NO. 148	5.6568543
GRID NO. 149	6.4031242
GRID NO. 150	7.2111025
GRID NO. 151	5.0990195
GRID NO. 152	5
GRID NO. 153	5.0990195
GRID NO. 154	5.3851648
GRID NO. 155	5.8309519
GRID NO. 156	6.7603624
GRID NO. 157	7.0710678
GRID NO. 158	6.0827625
GRID NO. 159	6
GRID NO. 160	6.0827625
GRID NO. 161	6.3245553
GRID NO. 162	6.708204
GRID NO. 163	7.2111025
GRID NO. 164	7.0710678
GRID NO. 165	7.2801099
GRID NO. 166	7.6157731

DEGREE OF COMPACTNESS = 5.2323484

MARKET VALUE OF L1, L2, L3
FOR EACH GRID

GRID NO. 1	39599.999	0	0
GRID NO. 2	42240.999	0	0
GRID NO. 3	44000.999	0	0
GRID NO. 4	52800.999	0	0
GRID NO. 5	48399.999	0	0
GRID NO. 6	0 0	0	
GRID NO. 7	0 0	0	
GRID NO. 8	8799.9997	0	0
GRID NO. 9	35199.999	0	0
GRID NO. 10	70399.996	0	0
GRID NO. 11	65999.999	0	0
GRID NO. 12	26400.999	0	0
GRID NO. 13	35199.999	0	0
GRID NO. 14	0 0	0	

Table 5. Continued

GRID NO. 15	0 42570.999	0	
GRID NO. 16	87999.999	0	0
GRID NO. 17	87999.999	0	0
GRID NO. 18	87999.999	0	0
GRID NO. 19	87999.999	0	0
GRID NO. 20	52800.999	0	0
GRID NO. 21	30599.999	0	0
GRID NO. 22	83599.999	0	0
GRID NO. 23	87999.999	0	0
GRID NO. 24	87999.999	0	0
GRID NO. 25	87999.999	0	0
GRID NO. 26	87999.999	0	0
GRID NO. 27	87999.999	0	0
GRID NO. 28	65999.999	0	0
GRID NO. 29	87999.999	0	0
GRID NO. 30	87999.999	0	0
GRID NO. 31	87999.999	0	0
GRID NO. 32	87999.999	0	0
GRID NO. 33	87999.999	0	0
GRID NO. 34	87999.999	0	0
GRID NO. 35	65999.999	0	0
GRID NO. 36	52800.999	0	0
GRID NO. 37	74799.999	0	0
GRID NO. 38	0 40442.449	0	
GRID NO. 39	87999.999	0	0
GRID NO. 40	65999.999	0	0
GRID NO. 41	0 21285.5	0	
GRID NO. 42	26400.999	0	0
GRID NO. 43	0 42570.999	0	

Table 5. Continued

GRID NO. 44	87999.999	0	0
GRID NO. 45	87999.999	0	0
GRID NO. 46	87999.999	0	0
GRID NO. 47	87999.999	0	0
GRID NO. 48	87999.999	0	0
GRID NO. 49	87999.999	0	0
GRID NO. 50	22000.999	0	0
GRID NO. 51	13200.999	0	0
GRID NO. 52	17600.999	0	0
GRID NO. 53	8799.9997	0	0
GRID NO. 54	26400.999	0	0
GRID NO. 55	0 42570.999	0	
GRID NO. 56	87999.999	0	0
GRID NO. 57	87999.999	0	0
GRID NO. 58	87999.999	0	0
GRID NO. 59	87999.999	0	0
GRID NO. 60	87999.999	0	0
GRID NO. 61	79199.998	0	0
GRID NO. 62	8799.9997	0	0
GRID NO. 63	13200.999	0	0
GRID NO. 64	35199.999	0	0
GRID NO. 65	8799.9997	0	0
GRID NO. 66	8799.9997	0	0
GRID NO. 67	0 42570.999	0	
GRID NO. 68	87999.999	0	0
GRID NO. 69	87999.999	0	0
GRID NO. 70	87999.999	0	0
GRID NO. 71	87999.999	0	0
GRID NO. 72	87999.999	0	0

Table 5. Continued

GRID NO. 73	79199.996	0	0
GRID NO. 74	17600.999	0	0
GRID NO. 75	83599.999	0	0
GRID NO. 76	87999.999	0	0
GRID NO. 77	74799.999	0	0
GRID NO. 78	49399.999	0	0
GRID NO. 79	0 42570.999	0	
GRID NO. 80	87999.999	0	0
GRID NO. 81	87999.999	0	0
GRID NO. 82	87999.999	0	0
GRID NO. 83	87999.999	0	0
GRID NO. 84	87999.999	0	0
GRID NO. 85	87999.999	0	0
GRID NO. 86	79199.996	0	0
GRID NO. 87	87999.999	0	0
GRID NO. 88	87999.999	0	0
GRID NO. 89	87999.999	0	0
GRID NO. 90	87999.999	0	0
GRID NO. 91	52800.999	0	0
GRID NO. 92	0 42570.999	0	
GRID NO. 93	87999.999	0	0
GRID NO. 94	87999.999	0	0
GRID NO. 95	87999.999	0	0
GRID NO. 96	87999.999	0	0
GRID NO. 97	87999.999	0	0
GRID NO. 98	87999.999	0	0
GRID NO. 99	87999.999	0	0
GRID NO. 100	87999.999	0	0
GRID NO. 101	87999.999	0	0

Table 5. Continued

GRID NO. 102	87099.999	0	0
GRID NO. 103	79199.998	0	0
GRID NO. 104	52800.999	0	0
GRID NO. 105	0	31028.25	0
GRID NO. 106	0	42570.999	0
GRID NO. 107	0	42570.999	0
GRID NO. 108	0	42570.999	0
GRID NO. 109	0	42570.999	0
GRID NO. 110	0	42570.999	0
GRID NO. 111	0	42570.999	0
GRID NO. 112	0	42570.999	0
GRID NO. 113	0	42570.999	0
GRID NO. 114	0	42570.999	0
GRID NO. 115	0	42570.999	0
GRID NO. 116	0	34056.799	0
GRID NO. 117	0	4257.0998	0
GRID NO. 118	0	4257.0998	0
GRID NO. 119	0	42570.999	0
GRID NO. 120	0	42570.999	0
GRID NO. 121	0	42570.999	0
GRID NO. 122	0	42570.999	0
GRID NO. 123	0	42570.999	0
GRID NO. 124	0	42570.999	0
GRID NO. 125	0	42570.999	0
GRID NO. 126	0	42570.999	0
GRID NO. 127	0	42570.999	0
GRID NO. 128	0	42570.999	0
GRID NO. 129	0	38313.899	0
GRID NO. 130	0	2128.55	0

Table 5. Continued

GRID NO. 131	0	2128.55	0
GRID NO. 132	0	21285.5	0
GRID NO. 133	0	36185.35	0
GRID NO. 134	0	42570.999	0
GRID NO. 135	0	42570.999	0
GRID NO. 136	0	42570.999	0
GRID NO. 137	0	42570.999	0
GRID NO. 138	0	42570.999	0
GRID NO. 139	0	42570.999	0
GRID NO. 140	0	42570.999	0
GRID NO. 141	0	31928.25	0
GRID NO. 142	0	2128.55	0
GRID NO. 143	0	17028.4	0
GRID NO. 144	0	42570.999	0
GRID NO. 145	0	42570.999	0
GRID NO. 146	0	42570.999	0
GRID NO. 147	0	42570.999	0
GRID NO. 148	0	42570.999	0
GRID NO. 149	0	42570.999	0
GRID NO. 150	0	21285.5	0
GRID NO. 151	0	10642.75	0
GRID NO. 152	0	42570.999	0
GRID NO. 153	0	42570.999	0
GRID NO. 154	0	42570.999	0
GRID NO. 155	0	42570.999	0
GRID NO. 156	0	40442.449	0
GRID NO. 157	0	17028.4	0
GRID NO. 158	0	4257.0998	0
GRID NO. 159	0	21285.5	0

Table 5. Continued

GRID NO. 160	0	36185.35	0
GRID NO. 161	0	42570.999	0
GRID NO. 162	0	42570.999	0
GRID NO. 163	0	12771.3	0
GRID NO. 164	0	2128.55	0
GRID NO. 165	0	17028.4	0
GRID NO. 166	0	17028.4	0

TOTAL UNIVERSITY LAND MARKET VALUE = 8873765.3
INPUT PERCENT (.YX) CHANGE IN DATA FOR NEXT RUN
? ↑↑↑+

central campus to the total number of acres in the central campus gave the total university land acreage of approximately 130 acres. Of these 130 acres: 73.5 were commercial (L1), 56.5 were residential (L2), and 0 acres were other types of land (L3). The market value for L1, L2, and L3 were calculated for each grid, given the market value parameters L13 = 80 thousand dollars, L14 = 38.7 thousand dollars, and L15 = 0 dollars.

Another result was the slope of each grid which was measured on an interval scale described in Appendix B. Also the distance of each grid from the centroid of the campus, X = 5.5 and Y = 7.5, was calculated. All the results shown in Table 5 can be examined in detail by looking them up in Appendix B under the development of quantitative criteria.

CHAPTER V

VALIDATION OF THE SIMULATION MODEL

Validation was an essential requirement in simulation to establish confidence in this simulation model. Validity was defined as the degree of correlation between the phenomenon to be measured and the model. The validation procedure described in this chapter was for a first-time model. The simulation model was tested for its credibility in producing evidence that would convince university administrators that they should explore the model as a possible decision-making aid. Ultimately the model must be demonstrated to be an accurate and reliable predictor of event sequences and value variation. However, throughout this simulation emphasis was directed toward validation.

Validation Procedure

The procedure for validating this simulation model was referenced in Emshoff and Sisson (75). According to these authors, credibility is the only kind of validity test possible for a first-time model. Testing the credibility required a detailed examination of the internal structure of the model and of the data used for the estimated parameters. Also careful comparison with past historical data and good communication with the university administration were required for credibility.

The first step in the procedure was to state the purpose of the simulation model. The second step was to define the criteria in which the model was tested for validation. Model validation was tested in this sequence:

1. One must be assured the model performed the way it was intended, using test data and, if available, real historical data.
2. Reasonableness was checked by:
   a. Showing that key subsystem models predicted their part of the world well (using historical data).
   b. Showing where parameter identification was required, that parameters could be fit (that the search terminated with a close match to historical data), and that the parameters had reasonable values.
   c. Having people who were knowledgeable about the situation (preferably including the decision-maker) review the model in detail and agree to its structure and parameters.
3. The decision-maker had an opportunity to explore the use of the model, to be familiar with its predictions, and to examine the interactions it implies. At this point, one must get agreement from the management as to what was a close enough fit between simulator output and actual data.
4. The model was used for decision-aiding. Careful records must be kept of its predictions and of actual results. (This may involve a time span of many years, so the evaluation procedure has to be set up carefully.) This criterion is a critical test of model validity because the degree of correlation between historical data and model output is tested.

The final step of the validation procedure was to run the model with more samples so that a comparison between the sample output could be more rigorously tested.

The validation of the simulation model followed these three steps: state the purpose, test the validity criteria, and run more samples. This procedure was applied to the simulation model and the validation of the model was pursued.

Validating the Simulation Model

The validation of the university simulation model was performed in two phases with both following the validity test sequence. Phase One was concerned with the validation of criteria against the phenomenon. Phase Two concentrated on the validation of the subsystem models against the phenomenon. Therefore, one could say that the simulation model was a valid replica of the university system if both phases were validated.

The purpose of the simulation model was to generate alternative courses of action and to stimulate consideration of the possible consequences associated with pursuing a particular alternative.

Phase One: Criteria Against Phenomenon

Criterion 1 of the validation test was met because real historical data were used to manipulate the criteria in the model. The criteria developed in the model performed to expectations with the real data.

Each subsystem was examined to check if the criteria predicted well their part of the real system. The land, buildings, and equipment components of the facilities subsystem were represented by length, space, time, and money criteria. All criteria developed with length, space, time, and money were valid because decades of past historical data have been recorded. Any further criteria developed with these four variables were considered valid. The entire set of criteria, developed for the people component of facilities and the value subsystem, were constructed from the aforementioned criteria; therefore, they were validated. The organizational subsystem contained a subset of criteria developed from money and another subset of criteria to evaluate organizational motivation; therefore, the set of criteria was partially validated. Another partially validated subsystem was transformation, which had a majority of the criteria constructed of length, space, time, and money. However, the remaining criteria lacked records of past historical data. Knowledge and communication criteria were partially validated too because a representative number of the criteria were valid.

All the parameters identified in the criteria set of the model had a one-to-one correlation with the real historical data. Some of the parameters were estimated by the university administrators which could be changed if a better fit with the real system was required. All the parameters were deterministic; therefore, statistical tests on parameter estimates were irrelevant. A parameter was defined as a characteristic or attitude of the system that had only one value over all foreseeable ranges of operation (but may change as different alternatives were studied) (76).

The criteria were examined by a university decision-maker while data were being collected for the simulation experiment. Every question that was asked by the decision-maker about the criteria was systematically answered to his satisfaction. Some criteria that the decision-maker reviewed were negotiated because these data were confidential and would not be released or the accuracy of the data were jeopardized. The overall set of criteria and parameters were agreeable to the university decision-maker.

Completing the validation tests on Criteria 3 and 4 will be recommended (see Chapter VII). Also, Step Three of the procedure was not satisfied because only one sample of data was used in the simulation experiment. The criteria were valid representations of the phenomenon as far as could be determined from the validation procedure that was followed. Further work on completing the procedure will be recommended.

Phase Two: Model Against Phenomenon

The subsystem models were tested with real historical data and their performance met all expectations. Therefore, the model performed as intended.

Each subsystem model predicted as well as its criteria predicted using real historical data. In Phase One the criteria were validated against the phenomenon; therefore, the subsystem models predicted well. All the parameters identified in the subsystem model equally matched the historical data. Therefore, the parameters had reasonable values, and the subsystem models had met this part of Criterion 2.

Several of the university's decision-makers reviewed the subsystems applicable to their responsibilities. The facilities subsystem was examined and accepted by two university decision-makers. Also the organizational model was accepted by a university manager. The communication model was thoroughly reviewed by one decision-maker, who accepted the initial structure of the student flow and faculty flow models. Some parts of the transformation and knowledge models should be examined by someone more knowledgeable in the area before these parts could be validated. For example, the Dean of Academics and

Registrar should examine these models in detail. The value model was entirely constructed of nonlinear financial models which were valid because their past performance was well established. Some parts of the subsystems were not scrutinized; however, every subsystem was partially reviewed and accepted by one or two university decision-makers. Therefore, the overall university model was acceptable to one set of university decision-makers.

The data-collecting process gave one decision-maker the opportunity to explore the use of the model. He became reasonably proficient with its predictions and the interactions it implied. Some questions arose about the accuracy of predictions in parts of the model. An agreement was reached with the decision-maker because it was pointed out that the predictions were initial attempts and rough representations of the real system. More opportunities should be given for testing this validity criteria; however, one decision-maker became reasonably familiar with the usefulness of the model.

Completing the validation test of Criterion 4 will be recommended (see Chapter VII). Also more than one sample of data were necessary to satisfy the final step of the validation procedure. As far as could be determined, up to the stopping point in the procedure, the models had successfully passed the tests on validity. The completion of the test procedure will be recommended as further development of this research.

In conclusion a procedure for validation of a first-time simulation model was proposed. The only kind of validity possible for a first-time model was to test the credibility of it. Stating the purpose, testing the credibility using validity criteria, and running more samples were the three steps of the validation procedure. The First Step of the procedure was accomplished. As many tests as permitted by the scope of this research on the credibility of the criteria against the phenomenon and the model against the phenomenon were made.

CHAPTER VI

CONCLUSIONS

The University System

An initial observation of the university indicated it was necessary to focus this research by enclosing the university with an abstract boundary. Further observations were made and they revealed the presence of several layers of functional elements which could be defined and modeled as a prototypal system. Each subsystem was probed to study their individual behavior as well as their interaction within the whole university system. There were inputs into this system which interacted with each subsystem. After the process was complete, outputs were observed leaving the structure. The principal result from this research was the conclusion that the university could be defined and modeled as a system.

The Systematic Search Into the Phenomenon

A systematic search was made and the behavior of the subsystems and their interrelationships summed to represent the behavior of the whole system. This systems approach to studying the university was the primary reason for ordering the subsystems in the sequence they appear. As the subsystems were overlayed, the frequency of interaction grew as well as the complexity of the individual subsystems. The systems methodology used in this study proved to be the essential tool in acquiring an understanding of the system structure.

The methodical investigation of the multi-layered structure of a university system defined fourteen subsystems and their interrelationships. Making the initial expansion of these subsystems gave an indication of the number of variables and relationships among variables that exist. To illustrate, over 250 variables were defined and each one interacted with two or more other variables. Further expansion of the system would introduce more variables and interrelationships. It was conclusive from the evidence found in this initial investigation that the university was a complex system.

The Evaluation Method

Trends in institutional research showed that evaluation methods were focusing on measures of input-process-output variables. The research literature stated that these measures were underdeveloped because the variables being measured were not traditional ones. Evaluative research was compatible in university systems and encouraged orderly experimentation.

Further evidence on the compatibility of evaluative research to a university system was observed in the real university experiment. The individuals at the university, who were responsible for the experimental data, demonstrated their confidence and interest in the development of quantifiable criteria. Therefore, the development of quantifiable criteria was acceptable in at least one university system.

The evaluative process presented in this study was approved by a university decision-maker. From the communication with the decision-maker, it was evident that accountability of actions was important in university systems. An efficient, valid, and productive tool was required before the decision-maker would implement it as a decision-aid. It was also observed that a systematic and orderly effect on the system would occur from the evaluation process. The evaluation process could improve the decision-making of university administrators; however, the validation procedure should be completed for further substantive results.

The reader is cautioned that the criteria developed in this thesis are not intended for adoption by any real system, but only demonstrate that quantifiable criteria can be developed from variables that are measurable.

Theory of Measurement

The variables in the model were selected on the basis that they could be measured on a ratio scale. This selection criterion assured the university model to have a high degree of credibility and mathematical flexibility. Also the university model contained several measures which were limited to the observable variables; therefore, other variables could appear after there are more iterations on the system. The principal conclusion drawn from these arguments was that all the variables in the model were measurable.

Value Theory

The multi-dimensional meaning of value was observed in the university system. To measure more than one value would be too extensive within the time limit of this research. However, the economic theory of value, based on the money criterion, offered the best approach to measure the value of objects in the university system. Every subsystem had variables that were measured based on the money criterion; therefore, value was the common integrator of the university system.

The Simulation Model

A thorough investigation of the university system was required to acquire an understanding of the system's behavior. Developing the simulation model cultivated a strong detailed understanding of the university system structure; therefore, its operation was more apparent. The transformation of the total system design to a simulation model resulted in a logical and mathematical representation of the university.

The prototypal model of the university system was simulated several times under varying conditions. Real historical data were used for the simulation experiment. The efficiency of the simulation model was high because of the computing efficiency of the UNIVAC 1108. The principal conclusion from the simulation experiment with the prototypal model was its efficiency and successfulness under varying conditions.

The credibility of the simulation model is proportional to the goodness-of-fit between the responses of the phenomenon and the replica. An examination of the model's internal structure and the data to estimate parameters were required before the model could be valid. The comparison between the model and historical data was accomplished through a systematic data collection procedure which revealed the model had a high degree of credibility. Also through the procedure of collecting data, sufficient communications were established with decision-makers in the university which was required for validating the model.

Evaluation and Simulation

The simulation model allowed the decision-maker to study the effect of an alternative solution on the system in a reasonable amount of time. Because the model performed efficiently, the decision-maker could analyze the effects of a decision in less than an hour, which included the time spent in the output queue at the computer center. Also the decision-maker could use a remote site to input the changes to the model which required fifteen minutes for a two-year forecast and proportionate amounts of time for five- ten-, and twenty-five-year forecasts. The implementation of the evaluation by simulation was efficient and an advantageous method in studying a system as complex as a university system.

Computational efficiency of the simulation model was a result of the equations characteristics. Deterministic instead of stochastic relationships were used primarily for modeling ease and efficiency. Also all the equations were linear except for the value subsystem where they were nonlinear. BASIC, the computer language used in the programming of the simulation model, offered the flexibility of a high-level language and the mathematical rigor of a scientific language. The BASIC language and system commands were comprehended quickly and applied to the particular requirement. It can be concluded from these arguments that modeling the university system was highly feasible.

The criteria developed for the evaluation were closely examined for their internal structure. Each subsystem had criteria which were highly credible because they had well established past histories. For example, length, space, time, and money were all strongly developed measures with voluminous amounts of historical data to support their validity. Those criteria developed without length, space, time, or money should be closely observed in future replications of the validation test.

Summary

The systems methodology presented a breakdown of the prototypal system into its subsystems. These subsystems were an initial attempt at modeling the whole university system, and a strong effort was made to design balanced models. One significant result of this initial effort was the potential to explore the models in more detail. A second result, the principal result of this research, was that a prototypal model had been designed.

CHAPTER VII

RECOMMENDATIONS

This research should provide the means to expand every subject referred to in the introduction. In these recommendations the most significant ones are summarized.

The University System

The principal recommendation coming from the study of the university system is that each subsystem should be expanded to a second-level of design, and the strategy should be to keep a balanced design. As each subsystem is expanded the interrelationships among them should be concurrently extended. Once the preceding design phase has been completed, the third iteration should be to move into the subsystem. For example, a major factor in the management of any system is allocating the resources which would require a separate investigation into the facility subsystem. Resource allocation models are prominent system methodologies and offer a future potential in extending this design.

Another recommendation resulting from this research is the six constrained subsystems--ethical, legal, moral, philosophical, power, and technology--should be actively designed. Each of these subsystems would require an individual and concentrated research effort. Once these designs have been added to the simulation model, the next step would be to add more subsystems to the system. Expanding the design of the university model should provide a resource for further development.

The Evaluation Method

In order to observe the benefits of this evaluation process in the decision-making environment, it is recommended that validity tests on the sample university be extended. The next test for validating the criteria against the phenomenon would be to give a decision-maker the opportunity to explore the use of the model. Finally, the model would be utilized to assist the decision-maker, and careful records would be kept of its predictions. These two steps in the validity tests would be the best proving ground to manipulate the simulation model.

A second recommendation would be to develop in more detail the criteria of the knowledge subsystem. In the initial attempt to develop the criteria, only the observable variables were measured; therefore, the criteria were limited. Adding other variables such as psychological, sociological, and environmental would improve the criteria in the knowledge subsystem. Also other subsystems could be improved by analyzing the criteria and determining a better representative of the real system.

Theory of Measurement

The organizational subsystem is the first model recommended for improving the application of measurement. Measurements of the variables in the equality-inequality section of the model were placed on the ordinal scale, but it would be desirable to have them on a higher scale. In effect, this means better measures of the power subsystem should be developed. This development would proceed concurrently with the design of the power subsystem.

In general, a more detailed expansion of the measures for the whole system is recommended. The first steps should proceed in parallel with the expansion of the subsystems. To illustrate, the extension into the land subsystem would progress by using a vernier scale on the grids, which means subdivide each grid into smaller grids. Also the transformation subsystem demonstrated the interrelationships with other subsystems by a few measures; subsequently, an expansion of the measurement theory application would be attractive in this subsystem.

Value Theory

That use of value which is based on the money criterion was the only one employed in this research. An immediate recommendation is to insert another value theory into the simulation model. Several theories of value were reviewed in the literature survey, and any one of them would offer a challenge to incorporate in the university model.

A less challenging recommendation is to improve the value measurements in the facilities subsystem. The addition of depreciation and appreciation variables in this subsystem would give a more balanced and realistic model.

Another recommendation would be to design a value model to measure the output value of students. A significant improvement would be a model that outputs data in which one could determine the breakeven point of their educational investment. This research should be pursued as a separate area of scientific inquiry.

The Simulation Model

Transforming a student from State N to State N+1 such that the knowledge of the student in State N+1 is greater than in State N is a process involving flow models of students and faculty. Student flow was the primary input to the transformation subsystem, and deterministic relationships were designed for every block that the student flows through. Implementing stochastic relationships are recommended in appropriate blocks where there would be a better representation of the real systems behavior.

Within the same student flow model, the equations were limited replicas of true flow equations. Flow equations should have a looping characteristic, such as input in State N+1 should be dependent upon output in State N. This relationship should be recursive. The flow equations in the model were externally connected; that is, the output from State N must be externally entered as input to State N+1. This break in the loop is a limit to the potential of the student flow model. The introduction of the recursive design is strongly recommended to the flow equations, but the basic student flow model should remain as the core of the structure.

Another recommendation is to increase the sensitivity of the dynamic subsystem by introducing another time-advance method, as in Chapter 7 of Emshoff and Sisson (77). Presently, the dynamic model handles the change of variables through time by a growth multiplier. This method is a rough approach to changing the value of the input and state variables. However, there is also flexibility in this approach because each subsystem can have different growth percentages. Therefore, the trade-off may be negative by introducing another time-advance method which means a further investigation is recommended.

Evaluation and Simulation

It is strongly suggested that an investigation be made into information system models to improve the communication model design. The communication model is a straightforward and deterministic representation of the real system. The existing research on information systems is technologically advanced and more representative of the behavior in a real communication subsystem. Models that singularly treat this area should be explored.

A more detailed design of the organizational subsystem, which includes only three components, is recommended for further development. The three components of equality-inequality, centralization-decentralization, and motivation demonstrated that a model could be designed. Several components such as the three-dimensional power matrix, group dynamics, game theory, and communication can be added to the model.

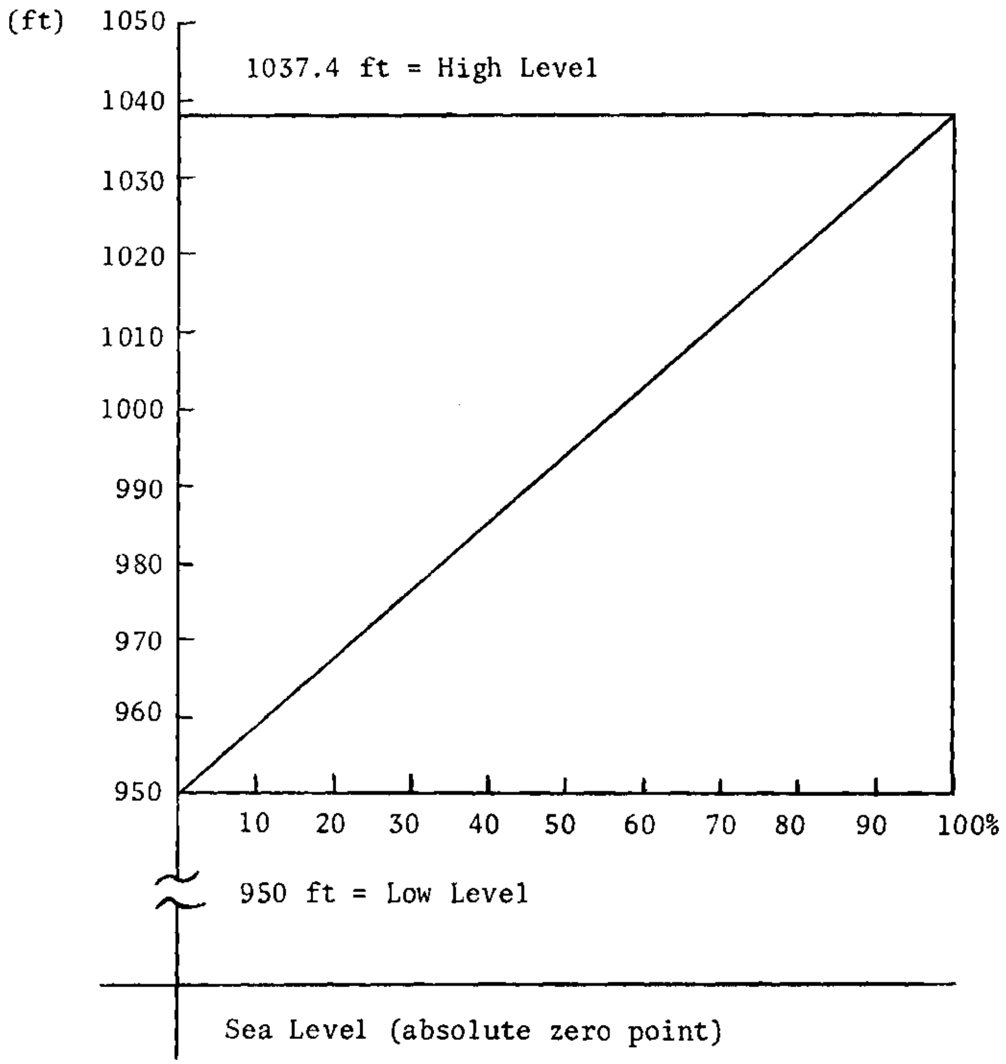
Summary

Several recommendations have been made, and there are more of lesser importance. There exist a tactical and a strategic recommendation which remain at the top of the list. The tactical recommendation is to build a data base by completing the validating procedure. From the data base, statistical tests and experiments could be applied to satisfy this area of validation. The strategic recommendation is to continue a more generalized anatomical development of the systems methodology.

APPENDIX A

I. A GENERAL APPROACH FOR CALCULATING THE SLOPE OF EACH GRID

II. AN EXAMPLE OF THE UNIFORM GRADIENT-SERIES FINANCIAL MODEL



Given the square feet above sea level of the centroid for each grid, the percent slope can be calculated.

Figure 11. A Procedure to Measure the Slope of a Grid

$$A = A_1 + g\left(\frac{1}{i} - \frac{n}{i}\left(\frac{i}{(1+i)^n - 1}\right)\right) = A_1 + g^{(A/G,i,n)} \qquad (1.1)$$

A_1 = Payment at the end of first year

g = Annual change or gradient

n = The number of years

A = The equivalent equal annual payment

A student receives an annual salary of \$8200 increasing at the rate of \$820 a year. The equivalent uniform salary for a period of 40 years if the interest rate is 7 percent compounded annually:

$$A = 8200 + 820\ (A/G,.07,40),$$

$$= 8200 + 820(11.4234),$$

$$= 8200 + 9367.188 = 17567.188.$$

Therefore, for a period of 40 years the product in a university will have an equivalent uniform salary of \$17,567.188 every year for 40 years.

APPENDIX B

DEVELOPMENT OF QUANTITATIVE CRITERIA

APPENDIX B

DEVELOPMENT OF QUANTITATIVE CRITERIA

Facilities

Criteria for each component of the facilities subsystem were separately developed. All the variables, except the slope of the land, were measured on a ratio scale for the facilities subsystem. The land component was considered first, and eight criteria were developed forming its subset.

1. Size L, was defined as the number of acres constituting the land of the university system

   1 GRID = 1 ACRE = 4848 square yards = 43,560 square feet.

2. Location was defined as follows (several definitions were available):

   L1 = Land located in an area that was > 50 percent commercial; that was retail space or office space.

   L2 = Land located in an area that was > 50 percent residential; that was populated space.

   L3 = Land located in an area that was other than L1 or L2.

3. External appearance of land was defined as follows:

   L4 = External appearance of land defined as flat; slope or grade $\leq$ 5 percent (70).

   L5 = External appearance of land defined as hilly; slope or grade > 5 percent.

   L16 = The slope of land as calculated by the method in Appendix A for hilly land, L5.

4. Usage of land was defined as land that was not vacant, L6, and land that was vacant, L7.

a. Percentage of nonvacant land to total land (L6/L).

b. Percentage of vacant land to total land (L7/L).

5. Degree of contiguity was defined as the percentage of dispersed land to total land of university system (L8/L).*

   L8 = Land that was disjointed from the central campus.

6. Centroid of land was defined as the center point of the central campus area (L9/2, L10/2).

   L9 = The number of grids on the X axis of the model.

   L10 = The number of grids on the Y axis of the model.

   a. The distance of each grid from the centroid

   $$\left[(L9/2 - L11)^2 + (L10/2 - L12)^2\right]^{\frac{1}{2}}$$

   L11 = The X coordinate of grid r.

   L12 = The Y coordinate of grid r.

7. Degree of compactness was defined as the average distance between the coordinates of the model grids and the centroid of the campus. Land that had a high degree of compactness had a small average distance, whereas a low degree of compactness had a large average distance (71).

There existed other desirable methods to measure compactness, such as geometric figures: high degree of compactness if the total university land had a circular boundary; average degree of compactness if the total university land had a square boundary; low degree of compactness if the total university land had another boundary.

8. Market value of land was best defined as the value of land using the money criterion. For each location: L1, L2, L3 there was associated a market value so each grid had three market variables: L13, L14, L15. The units were expressed

*Dispersed land was defined as land parcels not joined to the central campus.

in dollars per square foot, because it was a common unit of representation.*

a. The total university land market value (L13*L1 + L14*L2 + L15*L3).

Criteria were developed for the singular building component and the interrelationships between land and buildings. As the eleven criteria were explained, the building component variables, which constitute the criteria, were defined.

1. Total number of buildings, $\sum^{r} B17$, in the university system.
2. Total building space, $\sum^{r} B$, was defined as the volumetric space of a building in the university system for each grid r.

    a. Density of building space (B) to land area (L) for each grid r.

3. Land area occupied by a building, B', was defined as the land area space of a building in the university system for each grid r.

    a. Density of land area occupied by building (B') to land area (L) in each grid r.

4. Total space ($\sum^{r} B1, \ldots, \sum^{r} B12$) of each category in university system:

    B1 = lecture instructional space
    B2 = lab instructional space
    B3 = all other space
    B4 = student service space
    B5 = physical plant space
    B6 = administrative space
    B7 = faculty space
    B8 = athletic space
    B9 = housing space
    B10 = roadway, walkway, and parking space
    B11 = technological space
    B12 = library space

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*The market value variables L13, L14, and L15 were acquired from: Land Data Corporation, Commercial, Industrial, and Acreage Today, 1974; and Residential Today: DeKalb County, 1974-75 (14 Executive Park Drive, Atlanta, Georgia 30329).

5. The ratio of B1,...,B12 square feet to the total square feet of building space (B) for each grid r.

6. The total building space, $\sum^{r} B$, of the university system.

7. The ratio of total space per category ($\sum^{r} B1,\ldots,\sum^{r} B12$) to total building space ($\sum^{r} B$) of the university system.

8. Average building age for the university system (B13/B17).

   B13 = Average chronological age of the buildings in grid r.

9. Average building height for the university system (B14/B17).

   B14 = Average height (stories) of the buildings in grid r.

10. The distance, B15, of each grid from the centroid of central campus land.

11. The total replacement cost, $\sum^{r} B16$, of the buildings for the university system.*

    a. The replacement cost for one square foot of building space in each grid r.

    b. The average replacement cost of a building in the university system.

Criteria were developed for the equipment model and the land and building interrelationships. Several new developments of criteria, caused by the new input variables, were previously described in the system design section of Chapter III. These new variables and other input variables were defined, as they were introduced, in the eleven criteria developed for equipment.

The criteria were:

1. The population of equipment units, E, in each grid r (ΣE).

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*Replacement cost was the value of building space, based on the money criterion.

a. The total population of equipment units for the university system $(\sum^{r}\sum^{7}E)$.

2. The population of equipment units in each category for the university system $(\Sigma E1,\ldots,\Sigma E7)$.

   E1 = Technological equipment units
   E2 = Instructional equipment units
   E3 = Administrative equipment units
   E4 = Physical plant equipment units
   E5 = Athletic equipment units
   E6 = Student service equipment units
   E7 = Library equipment units

3. The total building surface area (floor space) occupied by the equipment, $\sum^{r}E8$.

   a. Average surface area (floor space) occupied per grid r (E8/N).

4. The equipment units category population density per building in each grid r (E1/B17,...,E7/B17).

   a. The equipment units category population density per building space in each grid r (E1/B,...,E7/B).

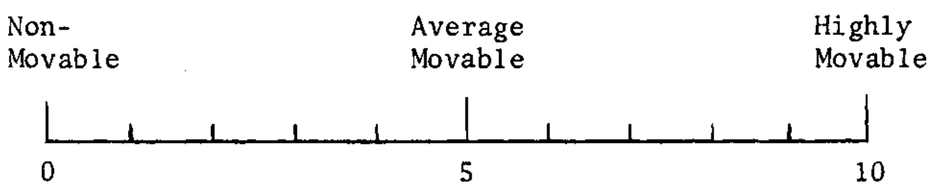
5. The equipment units total category population density per total university building space $(\sum^{r}E1/\sum^{r}B,\ldots,\sum^{r}E7/\sum^{r}B)$.

6. The ratio of equipment units per category to the total units in grid r $[E1/\sum^{r}(E1,\ldots,E7),\ldots,E7/\sum^{r}(E1,\ldots,E7)]$.

7. The ratio of total equipment units per category to the total equipment units of the university system $(\sum^{r}E1/\sum^{r}\sum^{7}E,\ldots,\sum^{r}E7/\sum^{r}\sum^{7}E)$.

8. Average mobility factor for the university system (E9/r).

   E9 = The average mobility factor for all the equipment in each grid measurable on a ten-point scale divided into intervals defined by the three levels: high, average, low.



9. Average age of the equipment for the university system ($E10/r$)

   $E10$ = The average chronological age for the equipment in each grid r.

10. The distance from the centroid of central campus, $E11$, of each grid r.

11. The total replacement cost, $\sum^{r} E12$, of the equipment for the university system.

    a. The average replacement cost of the equipment units in each grid r ($E12/\sum^{r} E$).

One assumption accompanied this component: a unit of equipment-A equaled a unit of equipment-B for each category.

Sixteen criteria were developed for the people component. Several interactive criteria were incorporated into the people component, because people overlay the other facilities components.

1. Total population of people per grid r ($\sum^{r} P$).

   P was defined as people.

2. Population of people, $P1$, which was defined as people in the salary range $0 \leq P22 \leq 4000$.

   Population of people, $P2$, which was defined as people in the salary range $4000 < P22 \leq 8000$.

   Population of people, $P3$, which was defined as people in the salary range $8000 < P22 \leq 12{,}000$.

   Population of people, $P4$, which was defined as people in the salary range $12{,}000 < P22 \leq 16{,}000$.

   Population of people, $P5$, which was defined as people in the salary range $16{,}000 < P22 \leq 20{,}000$.

   Population of people, $P6$, which was defined as people in the salary range $20{,}000 < P22 \leq 24{,}000$.

   Population of people, $P7$, which was defined as people in the salary range $24{,}000 < P22 \leq 28{,}000$.

Population of people, P8, which was defined as people in the salary range $28{,}000 < P22 \leq 32{,}000$.

Population of people, P9, which was defined as people in the salary range $32{,}000 < P22 \leq 36{,}000$.

Population of people, P10, which was defined as people in the salary range $36{,}000 \leq P22$.

3. Total population of people $(\sum^{r} \sum^{10} P)$.

4. Average population per grid (P/r).

5. Population density per building space for each grid r (P/B).

6. Population density per building for each grid r (P/B17).

7. Population density per square foot of land for each grid r (P/43560).

8. Population density per category per square foot of land for each grid r (P1/43560,...,P10/43560).

9. P11 = The number of daily hours an average person occupied assigned space for each grid r.

   P12 = The number of days in a school year.

   P13 = The number of days in a quarter or other system.

   a. Average percent daily occupancy ((P11/r)/8).

   b. Average percent quarterly occupancy ((P13*P11/r)/P13*8).

   c. Average percent yearly occupancy ((P12*P11/r)P12*8).

10. P14 = The number of daily hours an average person worked for each grid r.

    a. Average percent of daily work hours ((P14/r)/8).

    b. Average percent of quarterly work hours ((P13*P14/r)/P13*8).

    c. Average percent of yearly work hours ((P12*P14/r)/P12*8).

11. Absenteeism index of people for each grid (P17/P).

    P17 = The number of people absent from grid r.

12. Average mobility factor for each grid r.

P18 = The average mobility factor for all people in each grid determined from the criteria of high, average, and low movability on a scale 0-10.

a. System average mobility index (P18/r).

13. P19 was defined as the average chronological age of the people for each grid r.

    a. System average chronological age (P19/r).

14. P20 was defined as the migration index which is the number of years affiliated with system for each grid r.

    a. System average migration index (P20/P).

15. P21 was defined as the total educational background of the people for each grid r.

    a. System average educational background (P21/P).

16. P22 was defined as the average market value (salary) for each category of people in grid r.

    a. Average market value for each grid r $\left(\sum^{10} (P22*P)/P\right)$.

    b. Average market value of system $\left(\sum^{10} \sum^{r} (P22*P)/\sum^{r} P\right)$.

    c. System personnel cost based on average salary $\left(\sum^{10} \sum^{r} (P22*P)\right)$.

    d. Market value density of people per square foot of land in grid r $\left(\sum^{10} \sum^{r} (P22*P)/43560\right)$.

It was assumed that person A equaled person B, and work-hours A equaled work-hours B.

The quantitative criteria were developed for the facilities subsystem. It consisted of the four components: land, buildings, equipment, and people. All the variables, except slope of land, in the facilities subsystem were measured on a ratio scale.

Organization

Eighteen criteria were developed from the three anatomic components of the university organizational subsystem. Individual criteria represented each component, and these subsets converged to a set of criteria for which the evaluation of the organizational subsystem was based. The subsystem variables were defined along with the criteria development. Variables, representing the centralization-decentralization and motivation components, were measurable on a ratio scale. The hierarchical configuration based on the theory of equality-inequality reached the ordinal scale.

Hierarchical configuration:

1. The average market value of the people, 01, for each sublevel, 0', of the organization.

   a. The configuration of the organizational subsystem based on the theory of equality-inequality.

   b. The total market value concentration for each class.

   c. The total organizational value.

2. The concentration of people for each class.

   02 = The people in the organizational subsystem.

3. The frequency of sublevels, or inequality within each class.

4. The frequency of equality in the organizational subsystem.

5. The average age, 03, of the people for each class.

   a. The average organizational age for the system (03/7).

6. The migration index or total number years people were affiliated with the system for each class.

   04 = The total number of years people affiliated with the university system for each class.

   a. The average migration index for system (04/02)/7.

Centralization-decentralization:

7. The circular area of the system, resulting from the three step procedure in the subsystem model $(3.1416)*(05)^2$.

O5 = Average radius (miles) calculated from Step 3 in procedure.

Motivation:

8. Ratio of students accepted in state N, O6, to the students applied to system in state N, O7 (O6/O7).

9. Ratio of merit scholars entering system in state N, O8, to students applied in state N (O8/O7).

10. Ratio of students withdrawing from system in state N, O9, to the total student population in the system in state N, O10 (O9/O10).

11. Ratio of faculty applications to system in state N, O11, to faculty openings in state N, O12 (O11/O12).

12. Ratio of average daily absent students in state N, O13, to students registered in state N, O14 (O13/O14).

13. Ratio of average daily tardy students in state N, O15, to students registered in state N (O15/O14).

14. Ratio of students reentering system in state N, O16, to students recycled in state N-1, O17 (O16/O17).

15. Ratio of dollar funds granted for research to the system, O18, to total dollars of research grants of higher education: United States, O19 (O18/O19).

16. Ratio of recruiters seeking to interview the system product in state N, O20, to available recruiting openings in state N, O21 (O20/O21).

17. Ratio of B.S., M.S., D.S. degrees outputted by system, O22, O23, O24 in state N to the total B.S., M.S., D.S. earned degrees: United States, O25, O26, O27 (O22/O25, O23/O26, O24/O27).

18. Average organizational motivation factor for the system (O6/O7, ..., O24/O27)/12.

Transformation

One-hundred and one criteria were developed from variables unique to the transformation subsystem and also from interacting variables of other subsystems. This subsystem was the primary function of the university system, and most all variables from the other subsystems interacted with it. However, the criteria were developed systematically providing a strong base for evaluation.

From Figures 6, 7, and 8 of the model, one could see the quantity of new variables which represented this subsystem. Variables were from the student and faculty flows, the curriculum component, and variables which interacted from other subsystems. Paralleling the system model, criteria were developed in three phases: input, transformation, and output. To evaluate the total subsystem, one must base it on the summation of the three parts and not each phase exclusively.

The criteria were introduced in three groups representing each phase. Variables which form the criteria were defined, as soon as they were used. All variables were measured on a ratio scale. The basic assumptions were student A equaled student B, credit hour A equaled credit hour B, and course A equaled course B. The faculty flow model assumed faculty member A equaled faculty member B, work-hour for faculty member A equaled work-hour for faculty member B, course for faculty member A equaled course for faculty member B, and class for faculty member A equaled class for faculty member B.

Input Phase

1. Applicant flow to system for state N (T + T1).

   T = The first-time degree students applying for state N.

   T1 = The recycled students entering system for state N.

2. Ratio of first-time degree accepted to first-time degree applied for state N (T2/T).

   T2 = The first-time degree accepted students for state N.

a. Ratio of first-time degree enrolled to first-time degree accepted for state N (T3/T2).

T3 = The first-time degree students enrolled for state N.

b. Ratio of first-time degree enrolled to first-time degree applied for state N (T3/T).

3. Flow of students enrolled in system for state N of whole university system [(T5 + T6 - T7 - T8 + T3 - T4) = X1].

T4 = The first-time degree student withdrawals for state N.

T5 = The students outflow in system from state N-1.

T6 = The students recycled in system from state N-1.

T7 = The student withdrawals in system from state N-1.

T8 = The student deaths in system from state N-1.

4. Total students enrolled in each department for state N, T9.

a. Average first-time degree enrolled in department.

5. Total courses received by first-time degree enrollee (T3*T10).

T10 = The average number of courses preregistered by first-time degree enrollee.

6. Total hours received by first-time degree enrollee (T3*T11).

T11 = The average number of hours preregistered by first-time degree enrollee for state N.

7. Quality Control Factors:

a. The average class rank, T12, in previous educational system for first-time degree enrollee.

b. The average grade-point average, T13, in previous educational system for first-time degree enrollee.

8. Total hours provided by system to first-time degree enrollee for state N (T3*T11).

9. Total tuition fee dollars received from first-time degree enrollee by system for state N (T3*T11*T14).

T14 = System fee for one credit hour.

10. The hours dropped or added during registration, T113, per student for state N.

11. Total dollars budgeted to student by system for state N (T15*X1).

    T15 = Average money budgeted by system per student for state N.

12. Total student tuition dollars inputted to system for state N (X1*T15 + X1*T14*T11).

13. Total money received by system services and other activities (T16*X1).

    T16 = Fee paid by student for system services and other activities.

14. The average dollar student input to system (X1*T14*T11 + X1*T16)/X1.

Transformation Function Phase

15. The student inflow into system for state N (X1).

16. Ratio of the student population in each state N to the total student flow.

17. The average chronological age of the student flow for each state N, T17.

18. The average number of courses, T18, taken by student in state N.

    a. The total number of courses taken by student population in state N (X1*T18).

19. The average number of hours, T19, taken by student in state N.

    a. The total number of hours taken by student population in state N (X1*T19).

20. The average number of credit hours, T20, taken by student in state N.

    a. The total number of credit hours taken by student population in state N (X1*T20).

21. The average number of pass-fail hours, T21, taken by student in state N.

    a. The total number of pass-fail hours taken by student population in state N (X1*T21).

22. The average number of audit hours, T22, taken by student in state N.

    a. The total number of audit hours taken by student population in state N (X1*T22).

23. Total weekly classroom hours spent by student population in state N (T19*X1).

    a. Average time spent in classroom for a week by student in system (T19*X1)/X1.

24. Total fees paid to system by student population in state N (X1*T14*T19) + (X1*T16).

    a. Total money paid system by student flow $\sum^{N}$[(X1*T14*T19) + (X1*T16)].

25. Average hours dropped per student for state N (T23/X1).

    T23 = Total hours dropped by student population for state N.

    a. Total hours dropped per state N by students.

    b. Ratio of hours dropped to hours registered in system for state N (T23/X1*T19).

    T24 = Dollar per hour teaching market value for average faculty member.

    c. The cost for dropped courses in state N (T14*T23*3.1) + (T23*T24).

    d. Total system cost for state N for courses dropped by students $\sum^{N}$[(T14*T23*3.1) + (T23*T24)].

    e. The cost to the system per student for courses dropped in state N $\sum^{N}$[(T14*T23*3.1) + (T23*T24)]/X1.

26. Input to the preregistration element of the student flow (registered hours - dropped hours) [(T19*X1) - T23].

27. Average number of hours preregistered by student for state N+1.

    T26 = Average number of preregistered hours per student for state N+1.

    a. Total hours preregistered by students for state N+1 (X1*T26).

28. Average number of credit hours preregistered by students for state N+1.

    T27 = Average number of credit hours preregistered by students for state N+1.

    a. Total number of credit hours preregistered by students for state N+1 (X1*T27).

29. The average number pass-fail hours preregistered by students for state N+1.

    T28 = Average number of pass-fail hours preregistered by students for state N+1.

    a. Total number pass-fail hours preregistered by students for state N+1 (X1*T28).

30. The average number of audit hours preregistered by students for state N+1.

    T29 = Average number of audit hours preregistered by students for state N+1.

    a. Total number of audit hours preregistered by students for state N+1 (X1*T29).

31. Total preregistered hours by student flow for state N+1

    $\sum^{N}$(T27 + T28 + T29)*X1.

32. Student absenteeism index for system (T30/X1).

    T30 = Number of students absent from class for state N.

    a. Average cost per absent student in state N (T31/T30)*T14.

    T31 = Total hours students absent from class for state N.

Facilities Subsystem

Land:

33. Density of student population per square foot of land (L) for state N (X1/L*43560).

34. Ratio of land market value to student population for state N

    $\sum^{r}$(L13*L1 + L14*L2 + L15*L3)/X1.

35. The number of weekly class periods, T32, per acre of land for department in state N (T32/T33).

    T33 = Percent of an acre or grid in which department M occupied.

    a. Number of daily class periods per acre of land for state N (T32*.33)/T33.

36. Land cost for average size classroom per department M

    $[\sum^{r}(L13*L1 + L14*L2 + L15*L3)/L*43560]*T34.$

    T34 = The number of square feet in an average classroom for department M.

37. Density of student population per square foot of housing land for state N (X1/T35).

    T35 = Square feet of housing land in university system $(\sum^{r} B9)$.

38. Ratio of housing land market value to the student population for state N

    $[(\sum^{r}(L13*L1 + L14*L2 + L15*L3)/L*43560)/X1]*T35.$

    Buildings:

39. Square feet of volumetric space of category I and II (B1,B2) in department M for state N, T36.

40. Weighted students to building space I and II ratio in department M for state N (T19*X1)/(T36*T37) (72).

41. Average hours that building space I and II was occupied weekly in department M for state N, T37.

42. Weighted students to building space XI (B11) ratio in department M for state N (T19*X1)/(T38*T39) (72).

    T38 = The square feet of volumetric space of category type XI (B11) in department M for state N.

43. Average hours that building space XI was occupied weekly in department M for state N, T39.

44. Utilization of faculty space, (B7), as a percent of occupancy on a daily, quarterly, or yearly basis in department M for state N (T41*T40/T40).

    T40 = Amount of faculty space for department M.

T41 = Percentage of space occupied by faculty: daily, or quarterly, or yearly.

45. Density of student population per housing space (B9) for state N (X1/B9).

46. Average rental fee per square foot of housing space for state N (T42*T25*X1)/B9.

T42 = Rental fee paid for housing assuming a quarterly rent.

T25 = Percent total student population living in university housing.

47. Density of students per library space (B12) for state N (X1/B12).

48. Density of students per food service space for state N (X1/T43).

T43 = Food service percent of building space IV (B4).

49. Density of students per health service space for state N (X1/T44).

T44 = Health service percent of building space IV (B4).

50. Average replacement cost per square foot of classroom space, T45, in department M for state N (T45')*T45.

T45' = Average number of square feet in classroom for department M.

Equipment:

51. Weighted students to equipment type II ratio in department M for state N (T19*X1)/(T46*T47) (72).

T46 = The population of equipment type II (E2) for department M.

T47 = Average hours per week that equipment type II (E2) was used.

52. Weighted student to equipment type I ratio in department M for state N (T19*X1)/(T48*T49) (72).

T48 = The population of equipment type I (E1) for department M.

T49 = Average hours per week that equipment type I (E1) was used.

53. Weighted student to equipment type VII ratio in department M for state N (T19*X1)/(T50*T51) (72).

T50 = The population of equipment type VII (E7) for department M.

T51 = Average hours per week that equipment type VII (E7) was used.

54. Weighted faculty to equipment type II ratio in department M for state N (T52*T53)/(T46*T47).

T52 = Faculty population in department M for state N.

T53 = Average weekly periods that faculty teach for state N.

55. Weighted faculty to equipment type I ratio in department M for state N (T52*T53)/(T48*T49).

56. Average weekly utilization of equipment type II in department M for state N (T47).

57. Average replacement cost for equipment type II, T54, in department M.

a. Average replacement cost for equipment type I, T55, in department M.

People:

58. Faculty applicant flow into system for state N.

T56 = The faculty applicants in department M for state N.

59. Total faculty into system for state N

$$\sum^{M}[(T56 - T57 - T58 - T59 + T60)] = X2.$$

T57 = The faculty withdrawals in department M for state N.

T58 = The faculty deaths in department M from state N-1.

T59 = The faculty not accepted in department M for state N.

T60 = The faculty in department M from state N-1.

60. Faculty flow in department M for state N.

61. Total assistant, associate or tenured, full professor, and all others in department M for state N.

T61 = Assistant faculty member for state N.

T62 = Associate or tenured faculty member for state N.

T63 = Full faculty member for state N.

T64 = All other faculty members for state N.

62. Hours contracted for teaching, research, professional development, and community service in department M for state N (T65*X2, T66*X2, T67*X2, T68*X2).

T65 = Daily hours spent teaching and advising.

T66 = Daily hours spent in research.

T67 = Daily hours spent in professional development.

T68 = Daily hours spent in community service.

a. Hours contracted for teaching, research, professional development, and community service for system ($\sum^{M}$T65*X2, $\sum^{M}$T66*X2, $\sum^{M}$T67*X2, $\sum^{M}$T68*X2).

63. Average chronological age of faculty in system for state N (T69/X2).

T69 = Total chronological age of faculty in department M for state N.

64. Average migration index of faculty in system for state N (T70/X2).

T70 = Total years faculty in department M have been affiliated with system for state N.

65. Average teaching experience of faculty in department M for state N (T71/X2).

T71 = Total teaching experience of faculty in department M for state N.

66. Weighted student to teacher ratio in department M for state N (T9*T19)/(T52*T56) (72).

a. Weighted student to teacher ratio in system for state N (X1*T19)/(X2*T53) (72).

67. Frequency diagram of grades for faculty for state N.

T72 = Total grade A's for state N in department M.

T73 = Total grade B's for state N in department M.

T74 = Total grade C's for state N in department M.

T75 = Total grade D's for state N in department M.

T76 = Total grade F's for state N in department M.

68. The students passed for state N (T72 + T73 + T74 + T75).

a. The students recycled for state N (T76).

69. Ratio of students recycled to students passed for state N.

70. Total system market value for weekly teaching for state N [T77*(T65*X2)]/(52*40).

Total system market value for weekly research for state N [T77*(T66*X2)]/(52*40).

Total system market value for weekly professional development for state N [T77*(T67*X2)]/(52*40).

Total system market value for weekly community service for state N [T77*(T68*X2)]/(52*40).

T77 = Average faculty market value from people component.

71. The faculty leaving system in department M for state N, T78.

72. The faculty staying in system for state N (X2 - T78).

73. Ratio of the students to each counselor in system for state N (X1/T79).

T79 = Total system counselors for state N.

74. Ratio of the students to each physician in system for state N (X1/T80).

T80 = Total system physicians for state N.

Curriculum:

75. Total programs offered by system, T81, for state N.

76. The number of standard programs, T82, and the number of varying programs, T83, in department M for state N.

a. Ratio of varying programs to standard programs in department M for state N (T83/T82).

77. Total system program hours for state N $\sum^{M}$(T84).

a. Average program hours for a department M, T84, in the system for state N.

78. Total system program courses for state N $\sum^{M}(T85)$.

a. Average program courses for a department M, T85, in the system for state N.

79. Total 12-state degrees offered by system for state N, T86.

a. Total 16-state degrees offered by system for state N, T87.

b. Total 24-state degrees offered by system for state N, T88.

80. Average network time to graduate with a 12-state degree in system.

T89 = Average number of states it took for a student in department M to receive a 12-state degree.

81. Time series on a course in each department per year, T90.

82. Weighted student to credit hours ratio in department M, T91, for state N (T9*T91)/T84.

a. Weighted student to number of courses ratio in department M, T92, for state N (T9*T92)/T85.

83. Average market value of a program in department M for state N (T14*T84).

84. Average departmental market value for a 12-state degree, a 16-state degree, and a 24-state degree for state N (T93*T14), (T94*T14), (T95*T14).

T93 = Total credit hours required for a 12-state degree.

T94 = Total credit hours required for a 16-state degree.

T95 = Total credit hours required for a 24-state degree.

85. System market value for an average course for state N (T96*T14).

T96 = Average number of credit hours per course.

Organization:

86. Total colleges, T97, in system for state N.

a. Total departments, M, in system for state N.

87. The number of classes in department M for state N, T98.

88. Total number of classes in system for state N.

89. The number of students in department M for state N.

    a. The number of students per class in department M for state N (T9/T98).

Output Phase

90. The students passed, recycled, and non-recycled for state N.

    T99 = The students passed for state N.

    T100 = The students recycled for state N.

    T101 = The students non-recycled for state N.

91. The ratio of students passed to total student population for state N (T99/X1).

    a. The ratio of students recycled to total student population for state N (T100/X1).

    b. The ratio of students non-recycled to total student population for state N (T101/X1).

92. The frequency diagram for student output of state N of passed, recycled, and non-recycled.

93. The ratio of hours passed, T102, to the total student population [T102/X1].

    a. The ratio of hours recycled, T103, to the total student population [T103/X1].

94. The faculty leaving system for state N (T78).

    a. The faculty remaining in system for state N (X2 - T78).

95. Flow of graduating students from state N.

    T104 = The graduating students leaving system for state N.

96. The total graduating students for state N $\sum^{M}(T104)$.

97. Ratio of graduating students entering job market, T105, to flow of graduating students from state N (T105/T104).

    a. Ratio of graduating students entering state N+1, T106, to flow of graduating students from state N (T106/T104).

98. Ratio of actual network time: T107, T108, and T109 for a twelve-, sixteen-, and twenty-four-state degree respectively, to prescribed network time for state N.

99. Distribution of honors, T110, for twelve-state, sixteen-state degree, and twenty-four-state degree graduating students for state N.

100. Distribution of grade-point average, T111, for twelve-state degree, sixteen-state degree, and twenty-four-state degree graduating students for state N.

101. Market value, T112, distribution for twelve-state, sixteen-state degree, and twenty-four-state degree graduating students for state N.

Knowledge

The knowledge subsystem overlays the transformation subsystem; therefore, the criteria were strongly interrelated. Process and content criteria were developed around the primary variable, principles, and its interrelationship with the variables: grades, number of students per department, the number of credit hours registered per student, the number of faculty members in each department, the number of classes taught weekly by the faculty member, and the value for the knowledge content and process. It was assumed that a student who received a grade of A processed 100 percent of the principles taught in the course; one who received a grade of B processed 90 percent, a grade of C processed 80 percent, a grade of D processed 70 percent, and a grade of F processed 60 percent. The variables were defined when they were first used, and they were measurable on the ratio sacle.

The fifteen criteria for the knowledge subsystem are:

1. The number of principles per department M for state N (K).

   a. Total number of principles for the system.

2. The number of principles per student in department M for state N (K/K1).

   a. The number of principles per student systemwide for state N.

   K1 = The number of students in department M for state N.

3. The number of students receiving each principle in department M for state N (K/K2)*(K1*K3)/K.

   K2 = The total credit-hours offered by department M for state N.

   K3 = The average number of credit hours registered per student in department M for state N.

4. The number of principles per faculty member in department M for state N (K/K4).

   a. The number of principles taught by each faculty member in department M for state N (K/K2)*(K5).

   K4 = The number of faculty members in department M for state N.

   K5 = The average number of credit-hours taught weekly by faculty members in department M for state N.

5. The number of principles per credit-hour in department M for state N (K/K2).

   a. The number of principles per course in department M for state N (K/K6).

   K6 = The total number of courses taught in department M for state N.

6. The average number of principles for each class period in system for state N (K/K2).

7. The number of knowledge units learned by students in department M for state N [K12*(K/K2)*K3].

   K7 = The number of grade A's received by students in department M for state N.

K8 = The number of grade B's received by students in department M for state N.

K9 = The number of grade C's received by students in department M for state N.

K10 = The number of grade D's received by students in department M for state N.

K11 = The number of grade F's received by students in department M for state N.

Let K12 = (K7*1 + K8*.9 + K9*.8 + K10*.7 + K11*.6).

8. The value of type 1 knowledge, K13, which was defined as published books.

   a. Total type 1 knowledge content value.

9.* The value of type 2 knowledge content value which was defined as handouts or notes from professor (K14*K15)*1.1.

   K14 = The hourly teaching market value for average faculty member.

   K15 = The hours worked to prepare and publish materials.

   a. Total type 2 knowledge content value.

10.* The value of type 4 knowledge content which was defined as lab experiments (K14*K16)*1.2.

   K16 = The hours worked to prepare lab experiments.

11. The value of type 5 knowledge content which was defined as verbal and blackboard notes (K14*K17).

   K17 = The total hours which professors lectured in class.

   a. Total type 5 knowledge content value.

12. Total knowledge content value of system (K13 + K14*K15*1.1 + K14*K16*1.2 + K14*K17).

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*The constant multipliers represent the cost for relief time of the labor force.

13. The average market value for a principle in the system for state N [(K13 + K14*K15*1.1 + K14*K16*1.2 + K14*K17) + (K2*K18)]/K.

    K18 = The system cost for one credit hour.

14. Total knowledge content and process value for system (K13 + K14*K15*1.1 + K14*K16*1.2 + K14*K17) + (K2*K18).

15. Average hours spent per principle for each department (K15 + K16 + K17)/K.

All the assumptions stated in the transformation subsystem also applied in the knowledge subsystem. One other assumption was principle A equaled principle B.

Communication

Sixty-eight criteria were developed by separating the communication subsystem model into its components. Twenty-nine components were evaluated based on the criteria developed from the ten variables designed into the communication subsystem. The components were defined from the flow models in Figures 7 and 8 of the transformation subsystem and from the organizational subsystem. Specified criteria were used to measure the dollar value of a success or failure in the communication process for each component. The variables constituting the criteria were all measurable on a ratio scale.

These criteria were developed for the communication subsystem:

Student Communication Flow:

1. The C-N nodes for input to the transformation process for state N (C).

   C = The average number of C-N nodes for students for state N.

2. The applications received for state N (C1).

   C1 = The number of senders of communication for state N.

3. The acceptance letters sent to students for state N (C2).

   C2 = The number of receivers of communication for state N.

4. The frequency of devices used for input to the transformation subsystem (C3, C4, C5, C6, C7).

   C3 = Verbal communication device.

   C4 = Computer communication device.

   C5 = Written communication device.

   C6 = Telephone communication device.

   C7 = All other communication devices.

5. The total communication nodes for input (C8)*(C1/6).

   C8 = Average number of communication nodes per student for state N.

6. The overall average efficiency of input communication (C9/6).

   C9 = The average efficiency for each communication component.

7. The overall average timing index of input communication (C10)/C1.

   C10 = The number of late communications for state N.

8. The overall average timeliness of input communication (C11/6).

   C11 = The average number of days for communication to travel from sender to receiver for state N.

9.* The total number of circuit networks per student for input communication (C12)*(C2/6).

   C12 = The average number of circuit networks for state N.

10. The total number of feedback communication for student (C13)*(C2).

---

*A circuit network was defined as a communication linkage which involved a sender, receiver, and feedback to sender; in other words, a complete circuit.

C13 = The average number of feedback communications in state N.

11. The overall average noise received from input communication (C14).

    C14 = The average percent noise for each communication component for state N.

12. The dollar value for a successful input communication or a loss of input communication.

    C15 = The dollar value for a successful communication.

    C16 = The dollar value for a loss of communication.

13. The frequency of devices used for registration communication (C3, C4, C5, C6, C7).

14. The total communication nodes for registration communication (C8*C1).

15. The overall average efficiency of devices for registration communication (C9).

16. The overall average timing index for registration communication (C10/C1).

17. The timeliness of registration communication (C11).

18. The overall number of circuit networks for registration communication (C12).

19. The ratio of receivers to senders of registration communication (C2/C1).

20. The total number of feedback communications for registration (C13*C2).

21. The average noise received from registration communication (C14).

22. The dollar value for a successful registration communication (C15).

    a. The dollar value for a loss of registration communication (C16).

23. The overall number of C-N nodes for transformation process (C).

24. The overall communication nodes in classroom for transformation process (C8).

   a. The total communication nodes in classroom for transformation process (C8*C2).

25. Frequency of devices used for testing student in classroom (C3, C4, C5, C6, C7).

26. The average timeliness of testing communication (C11).

27. The average efficiency of classroom communication (C9).

28. The average percent noise in classroom communication (C14).

29. The dollar value for a successful classroom communication (C15).

   a. The dollar value for a loss of classroom communication (C16).

30. The frequency of devices used in transformation process (C3, C4, C5, C6, C7).

31. The overall average efficiency of communication in transformation process (C9/4).

32. The overall average timeliness of communication in the transformation process (C11/4).

33. The overall number of circuit networks for transformation process (C12).

   a. The total number of circuit networks for transformation process (C12*C2/4).

34. The ratio of receivers to senders for transformation process (C2/C1).

35. The overall average number of feedback communications (C13/4).

   a. Total number of feedback communication (C13*C2/4).

36. The overall average percent noise in transformation communication (C14/4).

37. The dollar value for a successful communication in the transformation process (C15).

   a. The dollar value for a loss of communication in the transformation process (C16).

38. The overall number of C-N nodes to graduate (C).

39. Frequency of devices used for graduation communication (C3, C4, C5, C6, C7).

40. Overall average efficiency of graduation communication (C9/4).

41. Overall average timeliness of graduation communication (C11/4).

42. Overall average number of circuit networks for graduation communication (C12/4).

    a. Total number of circuit networks for graduation communication (C2/4)*(C12).

43. Overall average number of feedback communications (C13/4).

    a. Total number of feedback communication (C13*C2/4).

44. Overall average percent noise in graduation communication (C14/4).

45. The dollar value for a successful graduation communication (C15).

    a. The dollar value for a loss of graduation communication (C16).

Faculty Communication Flow:

46. Overall number of C-N nodes in faculty communication flow (C).

47. The number of application letters received for state N (C1).

48. The acceptance letters sent for state N (C2).

49. The contracts signed for state N (C1).

50. Frequency of devices used for student tests (C3, C4, C5, C6, C7).

51. Average timeliness of feedback on tests to student (C11).

52. Average number of communication nodes for a faculty member (C8).

    a. Total number of communication nodes for faculty in system (C8*C2).

53. Frequency of devices used for faculty communication flow (C3, C4, C5, C6, C7).

54. Overall average efficiency of faculty communication (C9/8).

55. Overall average timeliness of communication flow (C11/8).

56. Overall average number of circuit networks for faculty communication (C12/8).

a. Total number of circuit networks for faculty communication (C12*C2/8).

57. Overall average number of feedback communications for faculty flow (C13/8).

a. Total number of feedback communication for faculty flow (C13*C2/8).

58. Overall average percent noise in faculty communication noise (C14/8).

59. The dollar value for a successful faculty communication (C15).

a. The dollar value for a loss of faculty communication (C16).

Organization

60. Frequency of devices used by organizational levels (C3, C4, C5, C6, C7).

61. Total number of C-N nodes for organizational communication (C).

62. Overall average efficiency of organizational communication (C9/5).

63. Overall average timing index of organizational communication (C10*C12).

64. Overall timeliness of organizational communication (C11/5).

65. Ratio of receivers to senders of organizational communication (C2/C1).

66. Overall average number of feedback communications for organization (C13*C2/5).

67. Overall average-percent noise of organizational communication (C14/5).

68. The dollar value for a successful organizational communication (C15).

a. The dollar value for a loss of organizational communication (C16).

Criteria to measure the value of communication of each subsystem component:

1. Successful communication value was new student dollar input to system; loss of communication value was new student dollar loss to system.

2. Successful communication value was new student dollar input to system; loss of communication value was new student dollar loss to system.

3. Successful communication value was (dollar cost to register student) + ($-overhead) + ($/hr-faculty) + ($-facility cost); loss of communication was negative value of above equation.

4. Criteria were not developed.

5. Successful communication value was student dollar input; loss of communication was negative value of student dollar input + ($10/student).

6. Successful communication value was student dollar input; loss of communication was negative value of student dollar input.

7. Successful communication value was (publishing costs) - (new student dollar input); loss of communication value was (publishing costs) + (new student dollar input).

7.5. Successful communication was ($/hr-faculty) + ($-student tuition input) + ($/hr-facility); loss of communication was twice the value of the above equation.

8. Successful communication was negative value of calculation found in transformation subsystem; loss of communication was difference between costs at t1 and costs at t2, where t1 was time communication was lost, and t2 was time where communication was restored.

9. Successful communication was the cost to register student which became a benefit; loss of communication was a cost to register student which became a negative value.

10. Successful communication was a ($/hr-faculty), which was a cost; loss of communication was a negative (2*$/hr-faculty) + ($-overhead).

11. Successful communication was a positive student dollar input to repeat request; loss of communication was a negative value of student input to repeat request.

12. Successful communication was graduation cost for student; loss of communication was twice the graduation cost for student.

13. Successful communication was average dollar contribution of each alumni; loss of communication was negative dollar contribution of average alumni.

14. Successful communication was average cost to process ($/hr); loss of communication was average cost for identical education which would be a cost to system.

Faculty Communication

1. Successful communication was market value benefit; loss of communication was market value cost.

2. Successful communication was market value benefit; loss of communication was market value cost.

3. Successful communication was market value benefit; loss of communication was market value cost.

4. Successful communication was market value increase benefit; loss of communication was market value decrease.

4.5. Successful communication was ($/hr-faculty) + ($-student tuition input) + ($-hr-facility); loss of communication was twice the above equation.

5. Successful communication was ($/hr) benefit to system; loss of communication was ($/hr) cost to system.

6. Successful communication was ($/hr) benefit to system; loss of communication was ($/hr) cost to system.

7. Successful communication was ($/hr) cost to system; loss of communication was (2*$/hr) cost to system.

8. Successful communication was ($/hr) cost to system; loss of communication was (2*$/hr) cost to system.

Organizational Communication

1. Successful communication was the overhead cost; loss of communication was twice the overhead cost.

Value

Several of the seventeen criteria were developed in previous subsystems, but value was necessary to complete the university model. The value criteria were summations of several variables which had been presented in the individual subsystem sections. However, the criteria developed in this section were more accurate, because the models in this subsystem were more representative of the physical system. The grid model was applied to develop criteria to evaluate the value centers of a system. The main objective of this model was to show the cost centers and benefit centers of the university system by applying the grid model.

The criteria for the four components of facilities were presented first, and a summation of the four components concluded this part of the model. Criteria of the organizational subset, transformation, knowledge, and communication followed facilities. A close look was taken at the value criteria for the transformation subsystem. Detailed criteria were developed into summations of several variables and were used to evaluate process value of the system. To conclude the evaluation of the value subsystem significant criteria were developed on the input-output relationship of the university system. The ratio of input value to output value was calculated, as well as the difference of input dollars and output dollars for each grid. All the variables contributing to the value criteria were measured on a ratio scale.

$X1 = (1 + V1)$

$X2 = (1 + V1)^{V2}$

V1 = The annual interest rate for the time period.

V2 = The number of interest periods.

1. The dollar market value of land for each grid (V3*X2).

   V3 = The dollar market value of an acre of land.

   a. The dollar market value of a square foot of land for each grid (X1*V3/43560).

   b. The total market value of university land.

2. The dollar replacement value of building space for each grid [V4*V5*X2 - (V4*V5*X2/50)*V6] = Z1.

V4 = The replacement value per square foot of building space for each grid.

V5 = The total number of square feet of building space for each grid.

V6 = The average chronological age of the buildings for each grid.

a. The dollar replacement value per square foot of space for each grid [V4*V5*X2 - (V4*V5*X2/50*V6]/V5.

b. The total replacement value of university building space.

3. The dollar replacement value of equipment for each grid [V8*V7*X1 - (V8*V7*X1/10)*V9] = Z2.

V7 = The replacement value per unit of equipment for each grid.

V8 = The total number of equipment units for each grid.

V9 = The average chronological age of the equipment units for each grid.

a. The average replacement value per unit of equipment (V7).

b. The total replacement value of university equipment.

4. The total market value, V10, of the people in each grid.

V11 = The population of people in each grid.

a. The average market value of people in each grid (V10*X2/V11).

b. The total value of people in university system.

c. The hourly value of people in each grid (V10*X2/40*V11*50).

5. The facilities subsystem value for each grid [X1*V3 + Z1 + Z2 + V10*X2].

a. The total facilities subsystem value of university system.

6. Total organizational value for each grid (V12 + V13)*X2.

V12 = Total market value of people in organization for each grid.

V13 = Total overhead of organization for each grid.

a. Total organizational value for university system.

7. Processing value for each grid (Z4).

   V14 = The number of days in school calendar for this year or quarter.

   V15 = Average cost per student to enroll in system for each grid.

   V16 = The student population in each grid.

   V17 = The total number of principles taught in each grid.

   V18 = The average dollar per principle for each grid.

   Z3 = [(V15*V16)*X2 + (V18*V17)*X2)].

   Z4 = [X2*V3 + Z1 + Z2 + V10*X4] + Z3.

   a. Processing value per day for each grid (Z4/V14).

   b. Total value for university system.

   c. Processing value per student for each grid (Z4/V16).

   d. Average processing value for student in university system.

8. The cost for dropping a course for each grid [(V19*V20)*(1 + 2 + .1) + (V20*V21)]*X2.

   V19 = The student cost for one credit hour.

   V20 = The total number of hours dropped in each grid.

   V21 = The average hourly market value of a faculty member for teaching in each grid.

   a. Total value for dropped courses in university system.

9. The cost for absenteeism in each grid (V19*V22)*X2.

   V22 = The total hours absent by students in each grid.

   a. The cost for absenteeism per student in each grid (V19*V22*X2)/V16.

   b. Total cost for absenteeism in university system.

10. The product value for each grid (V23*V24)*X3.

    V23 = Average market value for graduating students in each grid.

    V24 = The total number of graduating students in each grid.

The uniform gradient factor, based on 10 percent salary increase per year, 7 percent annual interest rate, and 40-year interest period, was X3 = (1 + .1*11.4234)*40.

a. Total product value for university system.

11. Ratio of processing value to product value for university system
$\sum^{r}[Z4/(V23*V24)*X3]$.

12. Ratio of processing dollar output to input for each grid (V23*V24)*X3/Z4.

13. Total dollar value for knowledge content in each grid [V17*V18*X2 + (1-V25)].

V25 = The percent depreciation of knowledge content for defined time period.

V26 = The total number of hours worked per topic for each grid.

a. The dollar value for knowledge content per hour for each grid [V18*X2(1/V26)].

b. Total knowledge content per hour for system
$\sum^{r}[V18*X2*(1/V26)]$.

c. Total knowledge content value in the university system
$\sum^{r}[V17*V18*X2*(1-V25)]$.

14. Value of communication for each grid (V27 + V28)*X2.

V27 = The total value of successful communications for each grid.

V28 = The total value of communication losses for each grid.

a. Ratio of the value in successful communications to the value of communication losses (V27/V28).

b. Total communication value in university system.

15. University system value for each grid (Z6).

Z6 = [(X2*V3 + Z1 + Z2 + V10*X2 + (V12 + V13)*X2 + Z7)].

Z7 = [(V15*V16)*X2 + (V17*V18)*X2*(1 - V25) + (V27 + V28)*X2].

a. Total university system value.

b. Estimate of the daily value of the university system
$(\sum^{r} Z6/V14)$.

16. Ratio of output value to input value for each grid
(V23*V24*X3 + V29)/Z6.

V29 = The dollar value of research output produced in each grid.

a. Total system output-input value ratio.

17. Output-input difference value for each grid
[(V23*V24*X3 + V29) - Z6].

a. Total university system output-input difference.

All the assumptions made in the previous subsystems were applied in the value subsystem.

Summary

Quantitative criteria were developed for every active subsystem. As each variable was used in the development, it was defined. All the assumptions made in the subsystems were stated and applied in the criteria. Summing all the criteria from every subsystem, the quantitative evaluation of the university system was developed.

APPENDIX C

SYSTEM SIMULATION MODEL

APPENDIX C

SYSTEM SIMULATION MODEL

Facility Model--Building

Mathematical Relationships

Inputting the data was accomplished by a R × C data array. These data were collected prior to running the model and were extracted from building blueprints. If data were not found for any element of the array a zero was placed which defined a null element. The data had to be collected from the same chronological time period. Only those grids which were occupied by buildings were considered in this model.

R = Total number of grids 1,2,...,r considered in the building component

C = 20 column data vector

C1 = Grid number; identified the data vector for each grid

C2 = Number of buildings in grid r

C3 = Amount of volumetric square feet for variable B1

C4 = Amount of volumetric square feet for variable B2

C5 = Amount of volumetric square feet for variable B3

C6 = Amount of volumetric square feet for variable B4

C7 = Amount of volumetric square feet for variable B5

C8 = Amount of volumetric square feet for variable B6

C9 = Amount of volumetric square feet for variable B7

C10 = Amount of volumetric square feet for variable B8

C11 = Amount of volumetric square feet for variable B9

C12 = Amount of volumetric square feet for variable B10

C13 = Amount of volumetric square feet for variable B11

C14 = Amount of volumetric square feet for variable B12

C15 = Total chronological age of buildings for each grid r

*C16 = X coordinate of grid r

*C17 = Y coordinate of grid r

C18 = Average height of buildings for each grid r

C19 = Amount of land area square feet occupied by the buildings for each grid r

C20 = Total replacement cost of buildings in grid r

These following equations were a selected subset of the equation set in the program.

1. To calculate the total volumetric space for the building component of the university system, a double summation equation was formulated. A(I,J) represented the data array, where J = 3,4,5,...,14 which were the column vectors representing B1,B2,B3,...,B12 type volumetric space respectively.

$$\sum_{I=1}^{r} \sum_{J=3}^{14} A(I,J) , \tag{9}$$

where I = 1,...,r grids of the building component. Similarly, the total volumetric space for each grid of the university subsystem was represented by the row vector, R(I), where

$$R(I) = R(I) + \sum_{J=3}^{14} A(I,J) \quad . \tag{10}$$

2. Sum the column vectors: C2,C3,C4,...,C15,C18,C20.

$$\sum_{I=1}^{r} (B17,B1,B2,\ldots,B12,B13,B14,B16)_I \quad . \tag{11}$$

3. The density of volumetric space for each square foot of land was represented by

$$R(I)/43560 \tag{12}$$

for each grid r. Another equation,

$$\sum_{I=1}^{r} (B')_I/43560 \quad , \tag{13}$$

was the density of the amount of land area occupied by the building for each square foot of land in grid r.

4. A ratio equation was used to describe the volumetric space density of each building category for the total volumetric space in grid r:

$$\sum_{J=3}^{14} A(I,J)/R(I) \quad . \tag{14}$$

5. This next equation resembled (14), except a column vector C(J) was defined. Vector C(J) was the total volumetric space for each category B1,...,B12. Again each category was represented respectively by column vector C3,...,C14; therefore, J = 3,...,14. In terms of the column vector C(J), the total volumetric space density of each category to the total volumetric space of the building component in the university system was given by

$$C(J) \Big/ \sum_{I=1}^{r} \sum_{J=3}^{14} A(I,J) \ , \tag{15}$$

where

$$C(J) = C(J) + \sum_{I=1}^{r} A(I,J) \ . \tag{16}$$

A(I,J) was the data array defined in equation (9).

6. Two averaging equations were utilized in the program. The first equation,

$$\sum_{I=1}^{r} (B13)_I \Big/ \sum_{I=1}^{r} (B17)_I \ , \tag{17}$$

was the average chronological age of a building on the university land. Similarly, the average height of a building was given by

$$\sum_{I=1}^{r} (B14)_I \Big/ \sum_{I=1}^{r} (B17)_I \ . \tag{18}$$

7. Value interrelated with every subsystem, and this was represented by the following equation. The replacement cost for a volumetric square foot of building space was given by

$$B16/R(I) \quad (19)$$

for each grid r.

Equations (11) through (19) were the mathematically relationships for the building component. These equations manipulated the data to output meaningful criteria from which one could evaluate the building component of facilities.

Operational Logic

Figure 12 shows the systematic flow of the simulation program for the building component. One process block references the distance equation (6) of the land model. This repetitive operation was performed in this model, because if anyone wanted to simulate this single module a meaningful criterion of distance was available. Variables L9 and L10 were passed from the land simulation program and used in calculating the distance of each grid r from the centroid of the university system.

The building simulation program passed three new parameters. Total volumetric space of the buildings on the university land, total volumetric space of the housing on the university, and the total library volumetric space joined the four previous parameters passed by the land model. This means that there are seven parameters being passed to the equipment model.

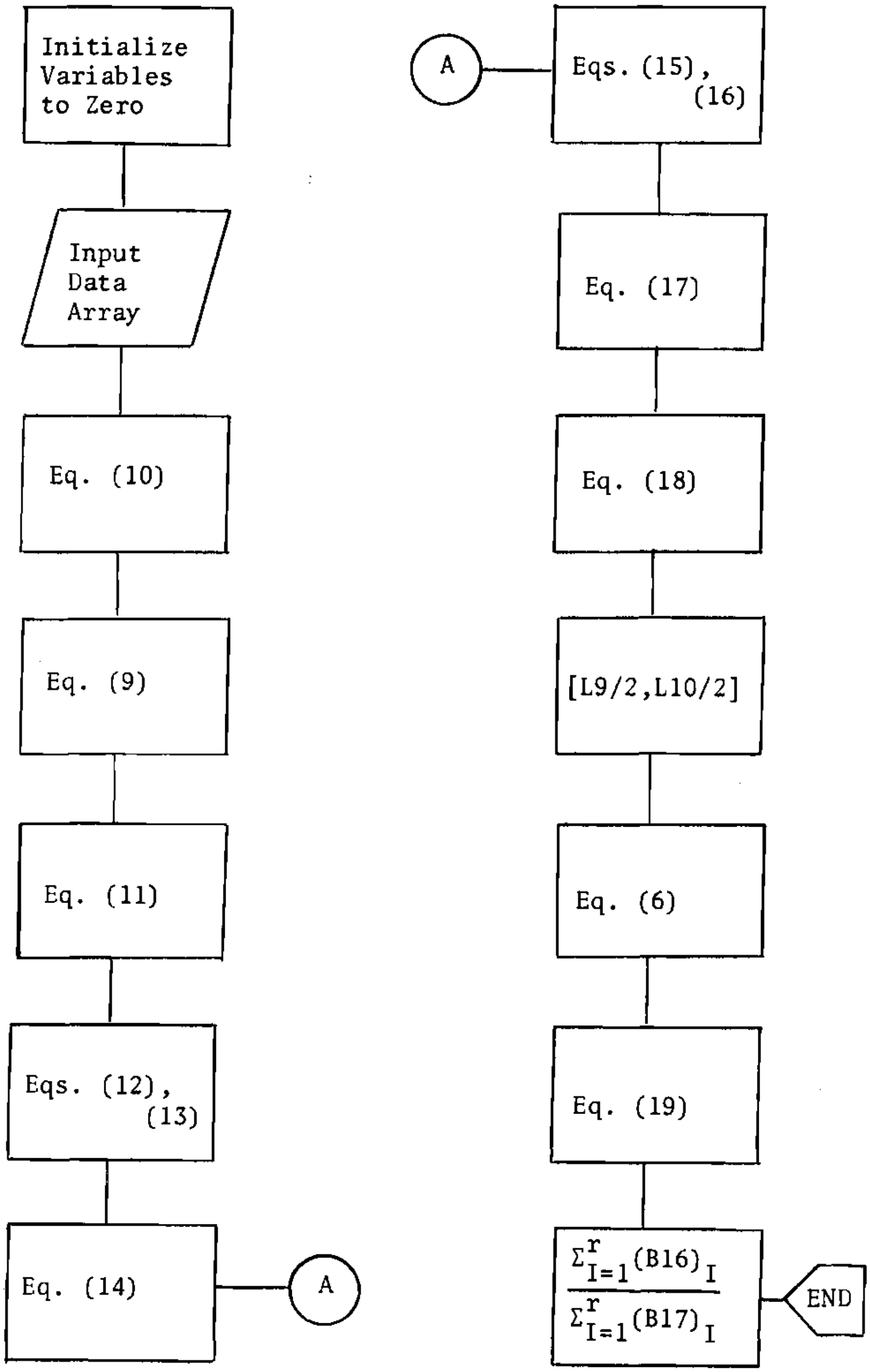

Figure 12. Facility Model--Building Component Logic Diagram

Facility Model--Equipment

Mathematical Relationships

The same procedure for inputting data was followed in this simulation model of the equipment. Similarly, the data were collected prior to running the model. Data on equipment were found in an inventory kept for the university system. If an equipment inventory was not kept by the university management, this data collection process could be laborious. The collected data were transformed into a data array having R × C dimensions.

R = Total number of grids 1,2,...,r considered in the equipment component

C = 16 column data vectors

C1 = Grid number; identified the data vector for each grid

C2 = Number of E1 equipment units

C3 = Number of E2 equipment units

C4 = Number of E3 equipment units

C5 = Number of E4 equipment units

C6 = Number of E5 equipment units

C7 = Number of E6 equipment units

C8 = Number of E7 equipment units

C9 = Total surface space occupied by equipment

*C10 = Total number of buildings in each grid r

*C11 = Total volumetric building space for each grid r

C12 = Average mobility factor for equipment in grid r

C13 = Average chronological age of equipment in grid r

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*Interrelated data elements from previous models.

*C14 = X coordinate of grid r

*C15 = Y coordinate of grid r

C16 = Total replacement cost of equipment in grid r

Several equations follow which were selected from the simulation program. These equations represented only a subset of the total number in the program.

1. To calculate the total number of equipment units in the university inventory for each grid a row vector was defined, R(I). For each I = 1,...,r, or grid, a summation of all the equipment was calculated. J = 2,...,8 were the respective column vectors in the array A(I,J) for equipment types E1,E2,...,E7. Therefore, the following equation summed all the equipment for each grid r:

$$R(I) = R(I) + \sum_{J=2}^{8} A(I,J) \ . \qquad (20)$$

In similar fashion, equation (9) of the building component,

$$\sum_{I=1}^{r} \sum_{J=2}^{8} A(I,J) = \sum_{I=1}^{r} R(I), \qquad (21)$$

gave the total number of equipment units in the university inventory.

2. Sum the column vectors C2,C3,...,C9,C12,C13,C16.

$$\sum_{I=1}^{r} (E1,E2,\ldots,E7,E8,E9,E10,E12)_I \qquad (22)$$

3. It was visible from these two following equations that equipment overlay buildings. The variable, B17, was defined as the number of buildings in grid r of the university system. Therefore, it followed that the equipment population density of each category for the total number of buildings for each grid r was

$$A(I,J)/B17 \ , \tag{23}$$

where J = 2,...,8, or the column vectors for each equipment category in array A(I,J). Also B, which was the building volumetric space in grid r of the university system, interacted with equipment giving this relationship,

$$A(I,J)/B \ , \tag{24}$$

which was the population density of equipment unit categories to the square feet of building volumetric space for each grid r.

4. From equation (24) one could derive

$$\sum_{I=1}^{r} A(I,J) \Big/ \sum_{I=1}^{r} B \ , \tag{25}$$

where J = 2,...,8. Equation (25) was the total population density of equipment unit categories to the total building volumetric space of the university system. Also the divisor was a parameter passed from the building simulation model.

5. A ratio of equipment units per category to total equipment units in grid r was given by

$$A(I,J)/R(I) \ , \tag{26}$$

for J = 2,...,8 which was respectively equipment type E1,...,E7. Summing equation (26) over all grids gave the ratio of total equipment units per category to total equipment units in the university inventory,

$$\sum_{I=1}^{r} A(I,J) \bigg/ \sum_{I=1}^{r} R(I) \ , \tag{27}$$

for each category J = 2,...,8.

6. The replacement cost for an average unit of equipment for each grid r was given by

$$E12/R(I) \ . \tag{28}$$

Equation (28) was similar to equation (19) in that they represented the value overlay of the facilities subsystem.

Operational Logic

Figure 13 is a diagram of the logical flow in the equipment simulation program. In like manner to the process followed in the building model, the distance equation (6) was referenced from the land mathematical relationships. The same argument held steadfast for this program which was to make available this meaningful measure for a simulation of the equipment model. The X and Y coordinates of the central grid were passed as parameters from the building model.

Parameters--total volumetric space of the housing and library in the university system, total university land acreage, and total university land market value--were carried through to the people model. Three parameters--the total volumetric building space of the university and the X and Y coordinates of the central grid--were dropped.

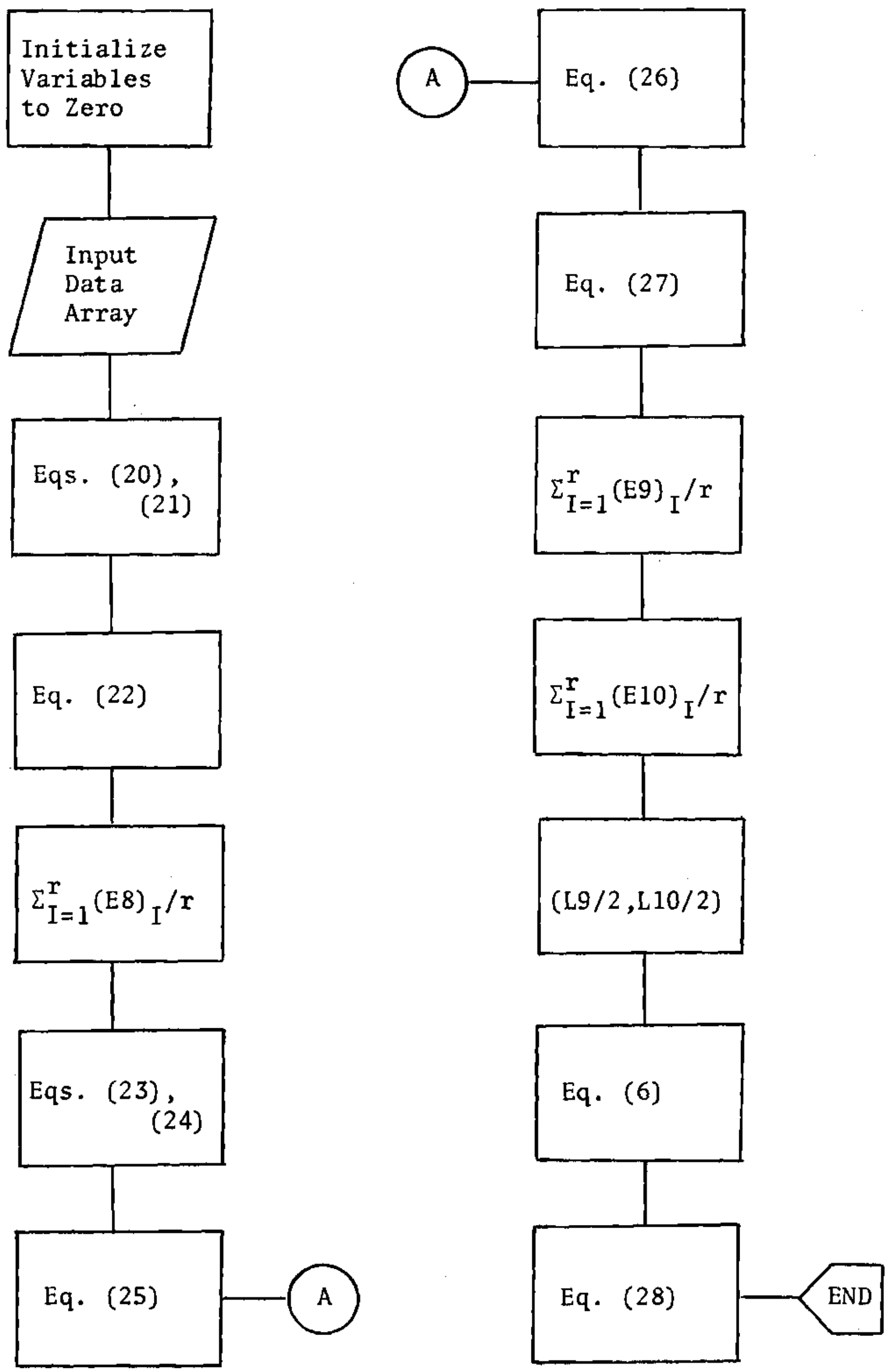

Figure 13. Facility Model--Equipment Component Logic Diagram

Facility Model--People

Mathematical Relationships

The people simulation model was the fourth and final program in the facility model. Data were inputted in the familiar fashion of the previous three simulation programs, a R × C data array. Data on the labor force at a university system were kept current and accurate; therefore, collecting these were a less arduous task than for the other simulation models. It was mandatory that the data be collected in the same chronological time period.

R = The total number of grids 1,2,...,r for evaluating the people component

C = 20 column data vectors

C1 = Grid number; identified the data vector for each grid

C2 = Number of people in range P1

C3 = Number of people in range P2

C4 = Number of people in range P3

C5 = Number of people in range P4

C6 = Number of people in range P5

C7 = Number of people in range P6

C8 = Number of people in range P7

C9 = Number of people in Range P8

C10 = Number of people in range P9

C11 = Number of people in range P10

*C12 = Total building space in grid r

*C13 = Total number of buildings in grid r

---

*Interrelated data elements from previous models.

C14 = Number of daily hours that average person occupied their assigned space in grid r

C15 = Number of hours that average person worked daily per grid r

C16 = The total number of people absent on average day in grid r

C17 = The average mobility index of people in grid r

C18 = The average chronological age of people for grid r

C19 = The total number of years people affiliated with system in grid r

C20 = The total number years of educational background for people in grid r

The following equations represent a subset of the equation set in the program.

1. Population of people in the university system for grid r was calculated using a row vector defined as P(I). Equation (20) was an exact replica. The population of people was calculated for grid, I = 1,...,r, where J = 2,...,11 were the respective column vectors in the array A(I,J) for people: P1,P2,...,P10. Therefore, the equation,

$$P(I) = P(I) + \sum_{J=2}^{11} A(I,J) \ , \tag{29}$$

was the population for each grid r. From equation (29) followed the total population of the university system, which was given by

$$\sum_{I=1}^{r} \sum_{J=2}^{11} A(I,J) = \sum_{I=1}^{r} P(I) \ . \tag{30}$$

Equation (30) was constructed identical to equation (21) with the difference being in the column vector notation.

2. Summed the column vectors J = 2,...,11 which was the population of each range of salary P1,...,P10,

$$\sum_{I=1}^{r} (P1,P2,P3,P4,P5,P6,P7,P8,P9,P10)_I \ . \tag{31}$$

3. The people component overlays the land, buildings, and equipment according to the system design. In the following equation, the overlay of people on buildings was demonstrated by this density expression,

$$P(I)/B \ , \tag{32}$$

for each grid r. Equation (32) was the density of people to the building volumetric space for each grid r. Similarly, the density of people to the buildings in each grid r was given by

$$P(I)/B17 \ . \tag{33}$$

4. Expanding these interrelated components of the facilities subsystem, one logically moved to land. The density of people per square foot of land acreage was,

$$P(I)/43560, \tag{34}$$

for each grid r. Equation (34) led to further detail by calculating the density of people per each category to the square foot of land acreage for each grid r. For J = 2,...,11 the density population of each category P1,...,P10 for each grid r was calculated by

$$A(I,J)/43560 \quad (35)$$

5. An evaluation of daily hours people occupied assigned space was calculated by determining the number of hours an average person occupied assigned space. The calculation for a percent yearly occupancy was

$$\left(P12 * \sum_{I=1}^{r} (P11)_I / r\right) \Big/ P12*8 \ , \quad (36)$$

where

$$\sum_{I=1}^{r} (P11)_I / r \quad (37)$$

was the average daily hours an average person occupied assigned space. For a percent daily occupancy,

$$\left(\sum_{I=1}^{r} (P11)_I / r\right) \Big/ 8 \ , \quad (38)$$

was the equation, and for a percent quarterly occupancy,

$$\left(P13 * \sum_{I=1}^{r} (P11) / r\right) \Big/ P13*8 \ , \quad (39)$$

was applied in the simulation model.

6. An equally important calculation was the number of daily hours an average person worked. Equation set five and this set were not intended to be used as criteria for evaluating the people of a university system. These sets of equations only demonstrated that one could evaluate the utilization of people resources. In similar fashion to equation (36), the percent of yearly work was given by

$$\left[P12^* \sum_{I=1}^{r} (P14)_I / r\right] \Big/ P12^*8 \ , \tag{40}$$

where

$$\sum_{I=1}^{r} (P14)_I / r \tag{41}$$

was the average daily hours an average person worked. For a percent of daily work,

$$\left[\sum_{I=1}^{r} (P14)_I / r\right] \Big/ 8 \ , \tag{42}$$

was the equation, and for a percent of quarterly work,

$$\left[P13^* \sum_{I=1}^{r} (P14)_I / r\right] \Big/ P13^*8 \ , \tag{43}$$

was used.

7. The absenteeism index was calculated by

$$P17/P(I) \tag{44}$$

for each grid r.

8. Value was the most important overlay of the people component. Every population range was calculated by categorizing people according to their market value. Several equations were utilized to manipulate the data and output appropriate criteria for the evaluation process. A data vector was inputted assigning an average market value to each population. Vector P22(J), where J = 1,2,...,10, contained the average market for each population: P1,P2,...,P10, in respective order. A(I,J) equals the elements in the R × C data array corresponding to the populations: P1,P2,...,P10. The population elements were A(I,2),A(I,3),..., A(I,11) respectively in the R × C data array. Therefore, the total market value for the population in grid r was given by

$$P'(I) = P'(I) + \sum_{J=2}^{11} P22(J-1)*A(I,J) \ . \tag{45}$$

P'(I) was redefined to represent the total market value for each grid r. Then dividing by the total population showed that the average market value for each grid r was given by

$$P'(I)/P(I) \ . \tag{46}$$

Equation (45) was rearranged to determine the average market value for the university system,

$$\sum_{I=1}^{r} P'(I) \Bigg/ \sum_{I=1}^{r} P(I) \ . \tag{47}$$

9. Once again the density of the market value to the square foot of land acreage for each grid r was given by

$$P'(I)/43560 \ . \tag{48}$$

Equation (48) carried the demonstration of the value interrelationships to the facilities subsystem one step beyond equation (34). Value overlays the people and the people overlay the land which described the multi-layered structure of the university system.

Operational Logic

The diagram of the logical flow in this model is described in Figure 14. Two new operations were demonstrated by the decision processes in the program. Each decision had to be made for the type of evaluation one was conducting. These decisions have to correlate with the chronological time period in which the data were collected. An example was a yearly, quarterly, or daily time period.

This simulation model did not utilize the parameters passed to it. However, the same parameters entering the people model also left it and were passed to the organizational simulation model. Total volumetric space of the housing and library building types, total university land acreage, and the total university land market value were carried over to the organizational model.

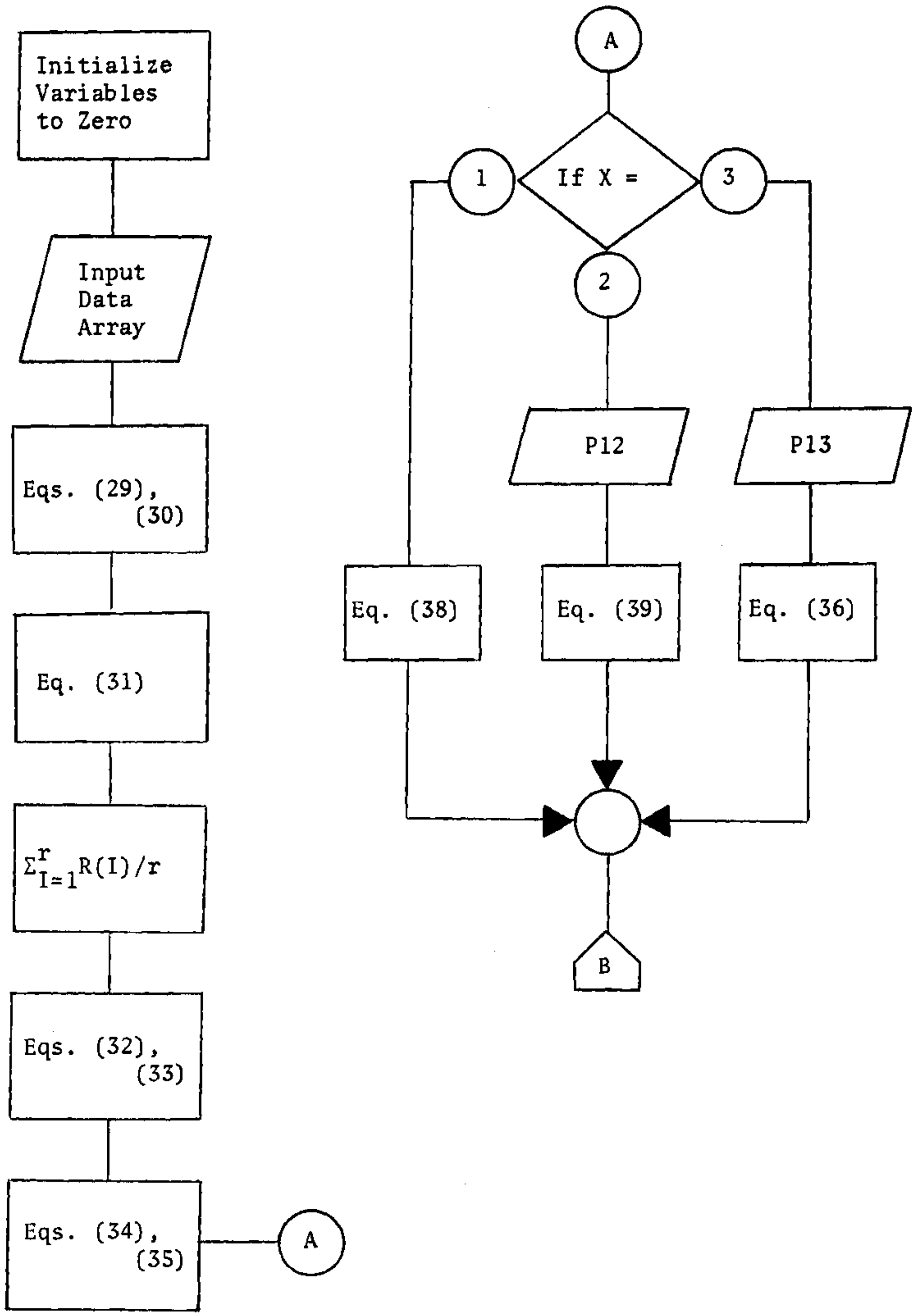

Figure 14. Facility Model--People Component Logic Diagram

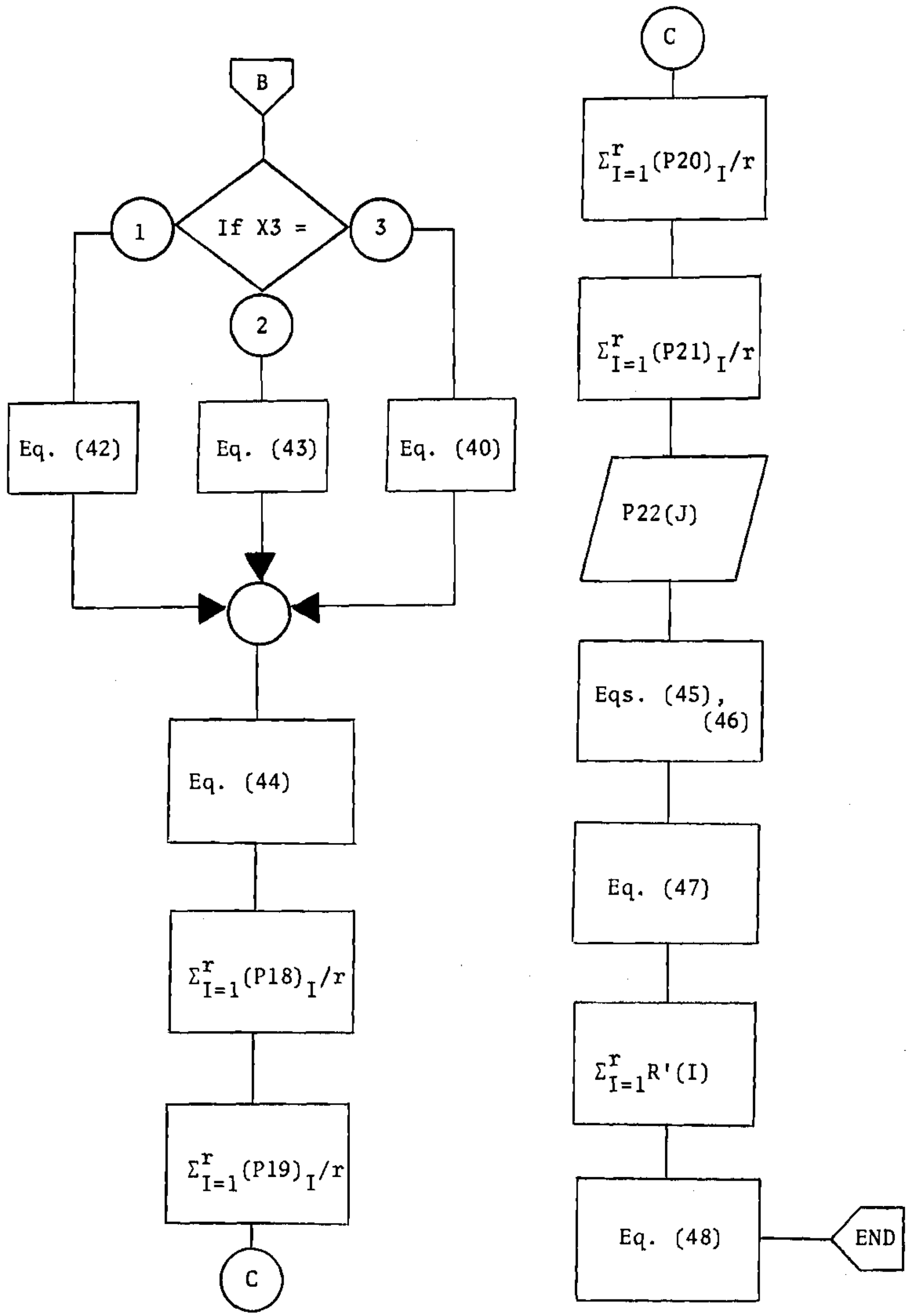

Figure 14. Concluded

Organizational Subsystem

Mathematical Relationships

The uniqueness of this simulation model was caused by the three-dimensional system design. A three-dimensional view of the hierarchical structure was simulated by a two-dimensional input array with R × C dimensions. Mathematical relationships permitted the three-dimensionality of the system. These data were collected in the same chronological time period as all other data for the simulation experiment.

Variables representing the organizational structure based on the theory of equality-inequality were measurable on the ordinal scale. All the other variables representing the centralization-decentralization component and motivational component were measurable on the ratio scale. Data feeding these measures were inputted by R × C array.

R = Seven organizational classes on the X-axis of the three-dimensional model

C = M + 5 column data vector where M equals the maximum number of sublevels found for any class of the organizational subsystem

C1 = Class 1 through 7 of the organizational subsystem

C2 = The population of people in each class

C3 = The number of sublevels for each class

C4 = The average chronological age of the population for each class

C5 = The total number of years population affiliated with system for each class

C6 = The average market value for sublevel 1 for each class

C7 = The average market value for sublevel 2 for each class

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.

CM = The average market value for sublevel M for each class

1. A row vector R(I) was defined to represent the sum of the average market values for each class

$$R(I) = R(I) + \sum_{J=6}^{M1} O1(I,J) \ , \qquad (49)$$

where O1(I,J) represented the average market value for sublevel J within class I. M1 = M + 5 which were the column data vectors in the array. Not all classes have M sublevels; therefore, a null element had to be inserted for those sublevels. The reason for this was programming inefficiency.

2. Then equation (49) can be used to calculate the total market value in a class

$$\sum_{I=1}^{7} O2*(R(I)/O')*1.2 \ , \qquad (50)$$

where O' was the number of sublevels in the class. The multiplier constant represented a factor for overhead which presented a more reasonable organizational value. Summing equation (50) was the total organizational value for the university system.

3. Measuring the centralization-decentralization component, the equation

$$(3.1416)*(O5)^2 \tag{51}$$

calculated the circular area of the university system. When comparing university system A and B, a smaller circular area means that the system was centralized; whereas, a larger circular area means one system was more decentralized than the other.

4. A series of ratios were used to measure the organization's motivational factor

$$O6/O7, O8/O7, O9/O10, O11/O12, O13/O14, \ldots, O22/O25, O23/O26, O24/O27. \tag{52}$$

Averaging the twelve ratios in equation (52) measured the average motivational factor for the organizational model.

Equations (49) through (52) were selected mathematical expressions from the organizational simulation model. However, these equations were only a portion of the entire simulation program.

Operational Logic

This operational logic was more elaborate than that of the four preceding models, because the evaluator must conceptualize a three-dimensional view of the organizational subsystem. The output projected enough data for the three-dimensional image to become vivid. Four parameters entered the model, and they were passed to the transformation model, where they were used in the mathematical relationships.

Figure 15 shows the flow diagram of the operational logic.

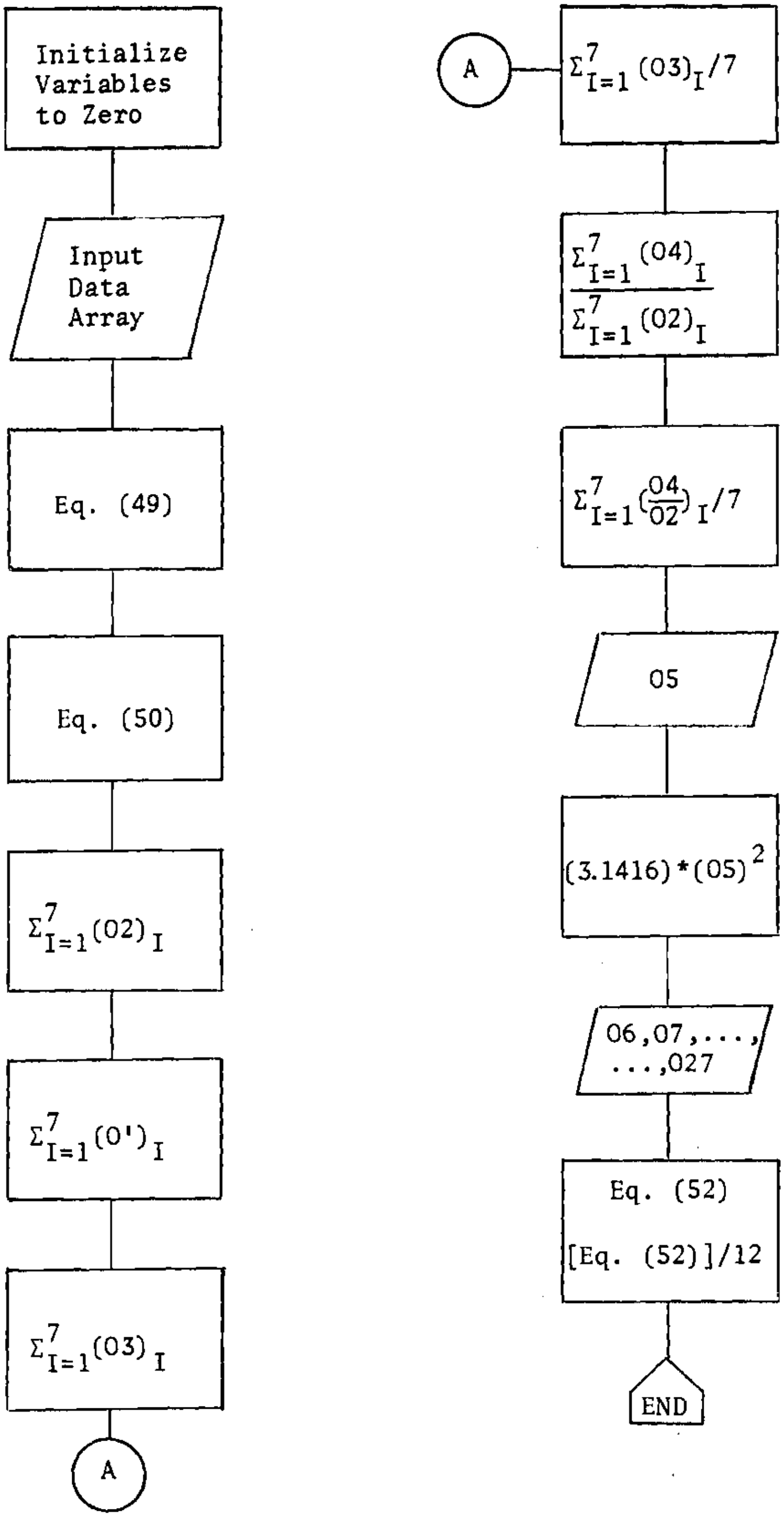

Figure 15. Organizational Model Logic Diagram

Transformation Model

Mathematical Relationships

The transformation simulation model required five data arrays. All five data arrays were inputted identically, just as every previous data array has been entered. It was required to collect the data in the same chronological time period.

Mathematical relationships from the input, transformation, and output phases are presented. Reference is made to the various components defined in each phase from the development of criteria in Chapter III. Student physical flow, value, and time constituted the input phase. Student and faculty physical flow, facilities, organization, curriculum, value, and time formed the components of the transformation phase. And the final portions of the student and faculty physical flows, value, and time composed the output phases. There was a high degree of interaction among the components in each phase. Because of the student and faculty physical flow models, there were two flow equations containing several variables each. Also these flow equations changed values through time; therefore, special treatment was given to designing the data arrays which fed these flows.

Five data arrays were used to input data to the three phases of the transformation simulation model. When each data array is introduced their dimensions will be defined.

Input Phase. One data array was used to input the student flow data. However, two separate data vectors were defined--the first vector which was a row vector defined the new student flow and the second vector was 2,...,N row vectors which defined the data for all other students. In other words, each row vector defined a state of the student flow. For example, the first row vector defined the first state of student flow or new students. The Nth row vector defined the Nth state of the student flow. Also the column vector of the data array was dimensioned dynamically. Columns 23,...,M depended upon the number of departments in the university system. For example, if M = 28 there were six departments in the university system.

The new student data vectors were defined as

R = State 1 of the student flow in the university system

C = 23,...,M column data vectors

C1 = The state of the student flow

C2 = The number of first-time degree applicants to the system for state 1.

C3 = The number of recycled students from state N-1 reentering the systems in state 1

C4 = The number of first-time degree students accepted for state 1

C5 = The number of first-time degree students enrolled for state 1

C6 = The number of first-time degree student withdrawals for state 1

C7 = The average number of courses preregistered by first-time degree students for state 1

C8 = The average number of hours preregistered by first-time degree students for state 1

C9 = The average number of credit hours preregistered by first-time degree students for state 1

C10 = The average number of pass-fail hours preregistered by first-time degree students for state 1

C11 = The average number of audit hours preregistered by first-time degree students for state 1

C12 = The tuition fee for one credit hour in state 1

C13 = Null vector

C14 = Null vector

C15 = The total hours dropped by first-time degree students for state 1

C16 = The average class rank in state N-1 of first-time degree students

C17 = The average grade point average in state N-1 of first-time degree students

C18 = Null vector

C19 = Null vector

C20 = Null vector

C21 = The total number of first-time degree students absent from classes on an average day for state 1

C22 = Null vector

C23 = The number of first-time degree students in department 1 for state 1

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CM = The number of first-time degree students in department M for state 1

All other student flow data for state 2,...,N were defined as,

R = 2,...,N states of the student flow in the university system

C = 23,...,M column vectors

C1 = The states 2,...,N of the student flow

C2 = The number of preregistered student output from state N-1

C3 = The number of recycled student output from state N

C4 = The number of student withdrawals from state N-1

C5 = The number of student deaths from state N-1

C6 = The average chronological age of students in state N

C7 = The average number of courses registered by students for state N

C8 = The average number of hours registered by students for state N

C9 = The average number of credit hours registered by students for state N

C10 = The average number of pass-fail hours registered by students for state N

C11 = The average number of audit hours registered by students for state N

C12 = The tuition fee for one credit hour in state N

C13 = Null vector

C14 = Null vector

C15 = Total number of hours dropped by students for state N

C16 = Null vector

C17 = The average number of hours preregistered by students for state N

C18 = The average number of credit hours preregistered by students for state N

C19 = The average number of pass-fail hours preregistered by students for state N

C20 = The average number of audit hours preregistered by students for state N

C21 = The total number of students absent from classes on an average day for state N

C22 = Null vector

C23 = The number of students in department 1 for state N

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CM = The number of students in department M for state N

1. The student physical flow equation for state 2,...,N was

$$\sum_{I=2}^{N} (T5 + T6 - T7 - T8)_I . \tag{53}$$

Given the new student flow, T3 - T4, the student flow equation in the university system was

$$X1 = \sum_{I=2}^{N} (T5 + T6 - T7 - T8)_I + T3 - T4 . \tag{54}$$

Equation (54) will be referenced as X1 in further equations involving the student physical flow.

2. A column vector L(J) was defined for J = 23,...,M. L(J) summed the student population for department 1,...,M of the university system across the system states 1,...,N. A(I,J) defined the data elements which were manipulated to find the student population for a department. Given the column vector

$$L(J) = L(J) + \sum_{I=1}^{N} A(I,J) , \tag{55}$$

the student population of department 1,...,M was calculated.

3. Value was defined earlier as an input to the transformation process along with student flow. This equation represented the total tuition or value input by first-time degree students

$$(T3*T11*T14) \quad . \tag{56}$$

To find the total student tuition value in the university system the dollars budgeted for each student was given as T15*X1. Adding the budgeted value and student input tuition value,

$$(X1*T15) + (X1*T11*T14) \tag{57}$$

gave the total student tuition value inputted to the university system.

Equation (57) was rearranged to calculate the total student value input to the system. This calculation excluded budgeted dollars, but included the student input value for system activities. Adding in system activity value, X1*T16, and omitting student budgeted value, X1*T15, equation (57) became

$$(X1*T16) + (X1*T11*T14) \quad . \tag{58}$$

Dividing through by the student flow

$$\left[(X1*T16) + (X1*T11*T14)\right]/X1 \quad , \tag{59}$$

the average dollar input to system by a student was derived.

4. Given equation (53) the percentage of the student population in state 2,...,N was

$$\sum_{I=2}^{N} (T5 + T6 - T7 - T8)_I / X1 . \tag{60}$$

5. A row vector, S(I), was defined as the student population in department 1,...,M for state I = 1,...,N. A(I,J) were the data elements which were manipulated to find the student population.

$$S(I) = S(I) + \sum_{J=23}^{M} A(I,J) \tag{61}$$

S(I) was used in a series of equations which the total number of credit, pass-fail, and audit hours were determined. Also the row vector was used to calculate the average time that a student spent in a classroom,

$$\sum_{I=1}^{N} S(I)*T19/X1 . \tag{62}$$

6. Similar to equation (58), the total fees paid the system by the students in state 1,...,N was given by

$$\sum_{I=1}^{N} \left[S(I)*T19*T14 + S(I)*T16\right]_I . \tag{63}$$

Summing equation (63) over all the system states gave the total input value of the student flow.

Transformation Phase.

7. The inputs to the system were expressed in equations (54) and (63). Inside the transformation model was the block representing dropped courses. The equation for deriving the value of dropped courses focused on student time, faculty time, and administrative time. In calculating dropped course value for administrative time it was assumed that the value was doubled because the slot vacated by the dropped student could have been filled by another student. Also an arbitrarily assumed 10 percent value was given for overhead in administrative time. Therefore, the value for a dropped course was given by

$$\sum_{I=1}^{N} [(T14*T23*(1 + 2 + .1) + T23*T24)]_I \qquad (64)$$

for each state N. Summing equation (64) over all the system states gave the total system negative value for a dropped course.

Dividing equation (64) by the student flow gave

$$\sum_{I=1}^{N} [(T14*T23*(1 + 2 + .1) + T23*T24)]_I/X1 \;, \qquad (65)$$

the system cost per student for a dropped course.

8. Another block, represented internally to the transformation subsystem, was preregistration. The total number of credit, pass-fail, and audit hours were found by summing

$$\sum_{I=2}^{N} \Big(S(I-1)*(T27 + T28 + T29)\Big)_I \tag{66}$$

over all the system states. The number of hours for state N+1 was calculated by equation (66).

9. Student absenteeism index was given by

$$\sum_{I=1}^{N} (T30)_I/X1 \tag{67}$$

for each state 1,...,N. Given, T31, the number of class hours absent by the student population on an average day, the value of student absenteeism per student was

$$\left(T31 \Big/ \sum_{I=1}^{N} (T30)_I\right)*T14 \; . \tag{68}$$

The transfromation subsystem overlays the facilities subsystem. In the transformation phase the facilities components of land, buildings, equipment, and people were defined. First, looking at the land, buildings, and equipment interaction with the transformation simulation model, another data array was inputted. This input data array was dimensioned R × C where R = M or the departments of the university system.

R = Department 1,...,M of the university system

C = 18 column data vectors for each department

C1 = Department identified for each row vector

C2 = Building space type I and II for department M

C3 = Average number of hours building space type I and II used weekly in department M for state N.

C4 = Building space type VII for department M

C5 = Average number of hours building space type IX used weekly in department M for state N

C6 = Building space type IX for department M

C7 = Average floor space size of a classroom for department M

C8 = Total type I equipment in department M

C9 = Average number of hours type I equipment used weekly in department M for state N

C10 = Total type II equipment in department M

C11 = Average number of hours type II equipment used weekly in department M for state N

*C12 = Total type VII equipment in department M + 1

C13 = Average number of hours type VII equipment used weekly in department M + 1 for state N

C14 = Average replacement cost for type I equipment in department M

C15 = Average replacement cost for type II equipment in department M

C16 = The percentage of a grid in which department M occupied

C17 = The number of faculty in department M for state N

C18 = Average number of weekly teaching hours of a faculty member in department M for state N

10. The passed parameter, total acreage of the university system, was used to calculate the density of the student population per square foot of land. Let L equal the passed parameter:

$$(X1/L*43560) \quad . \tag{69}$$

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*Library was defined as department M + 1 for simulation purposes.

Similarly, another passed parameter, total market value of university land, was used to find the ratio of land market value per student. Let C2 or equation (8), which was the summation of the land market value for locations L1, L2, and L3, equal the passed parameter:

$$(C2/X1) \quad . \tag{70}$$

Other interactive relationships with the land component were

$$\sum_{I=1}^{M} (T32/T33)_I \tag{71}$$

which was the number of weekly class periods per acre of land in department M. Multiplying (71) by .33 resulted in the number of daily class periods per acre of land in department M,

$$\sum_{I=1}^{M} (T32*.33/T33)_I \quad , \tag{72}$$

assuming each class met three hours weekly.

Given the market value for a square foot of land, C2/L*43560, the market value of the land for an average-sized classroom for department M was

$$\sum_{I=1}^{M} [(C2/L*43560)*T34]_I \quad . \tag{73}$$

Similar to equation (69) was the density of the student population to the square foot of housing land

$$X1/M3 \quad , \tag{74}$$

where $M3 = \sum^{r}(B9)_I$, the summation of housing space for the university system. The total housing space for the university system was a passed parameter. It was noted that the amount of housing space does not equal housing land unless the system has only one-story housing. Hence, equation (74) was an inaccurate derivation.

Given M3 from equation (74), the ratio of housing land market value to student population was

$$(M3*C2/L*43560)/X1 \quad . \tag{75}$$

11. Buildings were the second component which had a high degree of interaction with the transformation model. The first significant mathematical relationship with buildings was the weighted student ratio to type I and II space,

$$\sum_{I=1}^{M} [(T19*X1)/(T36*T37)_I \quad , \tag{76}$$

for department M. Similar to equation (76) was the weighted student ratio to type XI space,

$$\sum_{I=1}^{M} [(T19*X1)/(T38*T39)]_I \quad , \tag{77}$$

for department M.

Overlaying value on the transformation subsystem and building component one viewed a three-level interaction. Given M3 from equation (74) the average rental value per square foot of housing space was

$$(T25*T42*X1)/M3 \; . \tag{78}$$

The passed parameter, library space of the university system, was defined as M6. It interrelated with the transformation simulation model as the density of student population to library space:

$$X1/M6 \; . \tag{79}$$

12. Equipment was the third component interrelating with the transformation subsystem. A series of weighted student and faculty ratios were derived to represent the transformation subsystem overlay of equipment. First, the weighted student to equipment type II ratio was given by

$$\sum_{I=1}^{M} [(T19*X1)/(T46*T47)]_I \tag{80}$$

for department M. Weighted student to equipment type I ratio for department M was given by

$$\sum_{I=1}^{M} [(T19*X1)/(T48*T49)]_I \; , \tag{81}$$

and weighted student to equipment type VII ratio was

$$\sum_{I=1}^{M} [(T19*X1)/(T50*T51)]_I \tag{82}$$

for department M. Two weighted faculty ratios were derived for equipment type I and II. For type I the weighted ratio was

$$\sum_{I=1}^{M} [(T52*T53)/(T46*T47)]_I \tag{83}$$

for department M, and for type II

$$\sum_{I=1}^{M} [(T52*T53)/(T48*T49)]_I \tag{84}$$

was derived for department M.

People were the fourth component of facilities. Recall that the people component of the facilities subsystem excluded students. Students have been inputted to a flow equation, and they interacted with the people component, namely the faculty. Therefore, faculty were mathematically represented in a flow equation which received data from a data array. A third data array was defined to feed the faculty flow model. Faculty flow through the simulation model by department, and data were generated for them in every state N.

This third data array was dimensioned as R × C where R = M, or the number of departments in the university system.

R = Department 1,...,M of the university system.

C = 24 column data vectors for each department M

C1 = Department identified for each row vector

C2 = The number of faculty applicants in department M for state N

C3 = The number of faculty applicant withdrawals in department M for state N

C4 = The number of faculty deaths in department M for state N - 1

C5 = The number of faculty applicants not accepted in department M for state N

C6 = The number of faculty remaining in department M for state N

C7 = The number of assistant faculty in department M for state N

C8 = The number of associate or tenured faculty in department M for state N

C9 = The number of full faculty in department M for state N

C10 = The number of all other faculty in department M for state N

C11 = The number of teaching hours faculty contracted by department M for state N

C12 = The number of research hours faculty contracted by department for state N

C13 = The number of professional development hours faculty contracted by department M for state N

C14 = The number of community service hours faculty contracted by department M for state N

C15 = The total chronological age of faculty for department M

C16 = The total number of years faculty affiliated with department M

C17 = The total number of years teaching experience of faculty in department M for state N

C18 = The average number of weekly teaching hours taught by faculty in department M for state N

C19 = The total number of grade A given by faculty in department M for state N

C20 = The total number of grade B given by faculty in department M for state N

C21 = The total number of grade C given by faculty in department M for state N

C22 = The total number of grade D given by faculty in department M for state N

C23 = The total number of grade F given by faculty in department M for state N

C24 = The total number of faculty leaving department M in state N

13. The faculty flow equation into the university system was given by

$$X2 = \sum_{I=1}^{M} [T56 - T57 - T58 - T59 + T60]_I \ . \tag{85}$$

Future references to equation (85) will be made using X2. Rearranging equation (85), a row vector, P(I), was defined to represent departmental faculty flow. Faculty flow for department M was

$$\sum_{I=1}^{M} P(I) = \sum_{I=1}^{M} [T56 - T57 - T58 - T59 + T60]_I \ . \tag{86}$$

For example, P(1) was the faculty flow in department 1 of the university system.

14. Given the faculty flow in department M, one could determine the total hours spent in teaching, research, professional development, or community service. Total hours spent in teaching were calculated by

$$\sum_{I=1}^{M} P(I)*T65 \ , \tag{87}$$

in research by

$$\sum_{I=1}^{M} P(I)*T66 \ , \tag{88}$$

in professional development by

$$\sum_{I=1}^{M} P(I)*T67 \ , \tag{89}$$

and in community service by

$$\sum_{I=1}^{M} P(I)*T68 \tag{90}$$

for department M.

15. The interrelationship between the faculty and student flows was derived by calculating the weighted student to teacher ratio. Given the passed parameter, T19, which was the number of hours an average student was registered, the derivation became

$$\sum_{I=1}^{M} [(T19*X1)/\big(P(I)*T53\big)]_{I} \tag{91}$$

for department M. It was noted that a more accurate equation would consider only the student population in each department. Therefore, a more accurate equation was derived which calculated the weighted student to teacher ratio for the system.

$$(T19*X1)/\Big(X2*\sum_{I=1}^{M}(T53)/M\Big) \tag{92}$$

16. A column vector, Q(J), was defined to sum the grades over all departments. Columns J = 19,...,23 were vectors for grade A, B, C, D, and F respectively. Therefore, A(I,J) were the data

elements for the columns J = 19,...,23 and rows I = 1,...,M. Given vector Q(J),

$$Q(J) = Q(J) + \sum_{I=1}^{M} A(I,J) \ , \tag{93}$$

a frequency diagram of the grades given by the faculty for state N was Q(19) = T72, Q(20) = T73, Q(21) = T74, Q(22) = T75, and Q(23) = T76. Extending equation (93) the number of passing grades were given by

$$Q(19) + Q(20) + Q(21) + Q(22) \ , \tag{94}$$

and the number of recycling grades by Q(23).

17. Overlaying value on the faculty flow model was accomplished by calculating the market value for teaching, research, professional development, and community service. The market value for weekly teaching in the university system was formulated by

$$\left[T77 * \sum_{I=1}^{M} \left(P(I) * T65\right)\right] \Big/ (52*40) \ , \tag{95}$$

for weekly research,

$$\left[T77 * \sum_{I=1}^{M} \left(P(I) * T66\right)\right] \Big/ (52*40) \ , \tag{96}$$

for weekly professional development,

$$\left[T77 * \sum_{I=1}^{M} \left(P(I) * T67\right)\right] \Big/ (52*40) \ , \tag{97}$$

and for weekly community service,

$$\left[T77* \sum_{I=1}^{M} \left(P(I)*T68\right)\right] \Big/ (52*40) \ . \tag{98}$$

A fourth data array was inputted to the transformation simulation model for the curriculum component. Curriculum was that component of the transformation subsystem which outlined different certified processing routes for the student flow. Every program or curriculum route was assumed to be certified; therefore, the student flow could receive a twelve-state, sixteen-state, or twenty-four-state degree based on the curriculum path. Presently a twelve-state degree is equivalent to a bachelor's degree, a sixteen-state is equivalent to a masters, and a twenty-four state is equivalent to a doctorate, based on the quarter system. The data for the curriculum component were inputted through a R × C data array where R = M. It was required to collect the data from the same chronological time period.

R = Department 1,...,M of the university system

C = 18 column data vector for each department M

C1 = Department identified for each row vector

C2 = The number of programs or curriculum offered by department M for state N

C3 = The number of 12-state degrees offered by department M for state N

C4 = The number of 16-state degrees offered by department M for state N

C5 = The number of 24-state degrees offered by department M for state N

C6 = The number of standard programs in department M for state N

C7 = The number of varying programs in department M for state N

C8 = The average number of credit hours per program in department M for state N

C9 = The average number of courses per program in department M for state N

C10 = The average network time to graduate with a 12-state degree in department M for state N

C11 = The average yearly time-series a course was offered in department M

C12 = The number of credit hours constituting a 12-state degree in department M

C13 = The number of credit hours constituting a 16-state degree in department M

C14 = The number of credit hours constituting a 24-state degree in department M

C15 = The number of credit hours offered in department M for state N

C16 = The number of classes offered in department M for state N

C17 = The number of courses offered in department M for state N

C18 = The number of students in department M for state N

18. A column vector, C(J), was defined to sum the number of twelve-, sixteen-, and twenty-four-state degrees for the system. Columns J = 3, 4, 5 were vectors for a twelve-, sixteen-, and twenty-four-state degree respectively. Therefore, A(I,J) were the data elements for the columns J = 3, 4, 5, and rows I = 1,...,M. Given vector C(J),

$$C(J) = C(J) + \sum_{I=1}^{M} A(I,J) \ , \tag{99}$$

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*A standard program was one which was generally found in any university system.

the total twelve-, sixteen-, and twenty-four-state degrees: C(3) = T86, C(4) = T87, C(5) = T88 were summed for the system for state N.

19. Two ratios were derived to measure students to credit hours and students to courses. First ratio was weighted students to credit hours which could be found by

$$\sum_{I=1}^{M} [(T9*T91)/T84]_I \tag{100}$$

for each department M. Second ratio was similar to equation (100), except for an addition of the variable representing courses. Weighted students to courses was given by

$$\sum_{I=1}^{M} [(T9*T92)/T85]_I \tag{101}$$

for department M.

20. Value interacted with curriculum, given the market value of one credit hour. The market value of one credit hour was a parameter used in every phase of the transformation simulation model. It was not an internally passed parameter but externally passed. Given the value of one credit hour in the university system then the market value for a program was

$$\sum_{I=1}^{M} (T14*T84) \tag{102}$$

for department M. Equation (102) could be used to find the market value for a twelve-state degree:

$$\sum_{I=1}^{M} (T14*T93) \quad , \tag{103}$$

a sixteen-state degree:

$$\sum_{I=1}^{M} (T14*T94) \quad , \tag{104}$$

and a twenty-four-state degree:

$$\sum_{I=1}^{M} (T14*T95) \tag{105}$$

for department M.

The final component in the transformation phase was the organization. Using data from the curriculum data array and several externally passed parameters, the mathematical relationships for the organizational component were formulated. Including the organization component in the transformation phase demonstrated that the organizational subsystem was overlayed by the transformation subsystem. This overlay produced interrelationships between the subsystems.

21. An example of the interaction caused by the transformation subsystem overlay was the number of students per class. Class referred to a classroom in this case. Given the data from the curriculum data array the derivation was

$$\sum_{I=1}^{M} (T9/T98)_I \tag{105}$$

for department M. The rest of the mathematical expressions in the organizational component are shown in the operational logic.

Output Phase

Data elements for the output phase of the transformation subsystem were inputted by a fifth array. The output phase represented the outflow of students and faculty for State N of the transformation simulation model. Outflows from State N became the inflows for State N+1 and were essential for the dynamic operation of the university system. The data array construction supported this concept by representing the student outflow for each State N with a row vector. Recall that the construction of the student inflow data array was identical.

The output phase closed the loop between input and output in the transformation simulation model. It should be noted that closing the loop was an external rather than internal operation. In other words, the outflow from State N was externally inputted to the inflow of State N+1 rather than internally passed to the inflow. However, the external operation does not effect the dynamic operation of the simulation model.

Two outflow variables, student flow and value, were defined just as they were in the input flow. The graduating students had two choices, either to continue their education or enter the job market. The value outflow of the transformation subsystem was the market value of graduating students based on their degree level.

Faculty outflow was handled by passing a parameter from the faculty component of this simulation model. The number of faculty leaving the system in State N and the current faculty for State N were two parameters passed to show the flow of faculty for State N+1.

The output phase was designed as the element closing the loop of the transformation simulation model. Students flowing in the closed path returned as input to State N+1 while graduating students exited the closed path. Graduating students either left the system entirely or returned for further education. The faculty flow was updated by subtracting those leaving the system from the current state of the faculty. Data for the output phase were inputted in a R × C array. It was required to collect the data in the same chronological time period.

R = State 1,...,N of the university system

C = 14 column data vector

C1 = Identified the state of the student flow

C2 = The number of students passed in state N

C3 = The number of students recycled in state N

C4 = The number of students non-recycled in state N

C5 = The number of credit hours passed in state N

C6 = The number of credit hours recycled in state N

C7 = Identified the row vectors which contain the data for the graduating students in state N. For example in a quarter system the identification would be 12, 16, and 24

C8 = The number of graduating students for each identifier

C9 = The number of graduating students entering the job market

C10 = The number of graduating students continuing their education

C11 = The average network time to receive the degree

C12 = The number of honors for each degree

C13 = The average grade point average for each degree

C14 = The average market value of graduating student entering the job market for each degree

22. Summed the column vectors C2, C3, C4, C5, and C6,

$$\sum_{I=1}^{N} (T99, T100, T101, T102, T103)_I \ , \tag{107}$$

where I = 1,...,N states of the student flow.

23. Two parameters, the number of current faculty and the number of faculty leaving the system, were passed to find the number of faculty staying in the system. Given these two parameters the number of faculty staying in the system was found

$$X2 - \sum_{I=1}^{M} (T78)_I \ . \tag{107.1}$$

Recall that X2 was defined by equation (85).

24. Student outflow was equated to the number of graduating students. This was found by summing across the three rows identifying the graduating students and down C8

$$\sum_{I=1}^{3} (T104)_I \ . \tag{108}$$

Given equation (108) the percent of graduating students entering the job market was

$$\sum_{I=1}^{3} (T105)_I \bigg/ \sum_{I=1}^{3} (T104)_I \ , \tag{109}$$

and the percent continuing their education was

$$\sum_{I=1}^{3} (T106)_I \bigg/ \sum_{I=1}^{3} (T104)_I \ . \tag{110}$$

Operational Logic

The operational logic for the transformation simulation model was separated into four modules or programs. The first, second, and third modules were distinguishable because each module began with an input data array process. The fourth module began with the input process of the curriculum data array. Figure 16 shows the four modules as one continuous logic flow because the transformation subsystem was one subset of the university system.

Four parameters entered the first module from the organizational model: total volumetric space of the housing and library building types; total university land acreage; and the total university land market value. These same parameters left module one with the addition of the student flow parameter (X1). Entering module two were five parameters and everyone was utilized in the mathematical expressions. Leaving module two were the student flow parameter (X1) and the number of credit hours registered by an average student in State N. Again these parameters were utilized in module three. The student flow (X1) and two new parameters, the current faculty flow and the number of faculty leaving the system in State N, were passed to the fourth module. All three parameters were zeroed out in the fourth module;

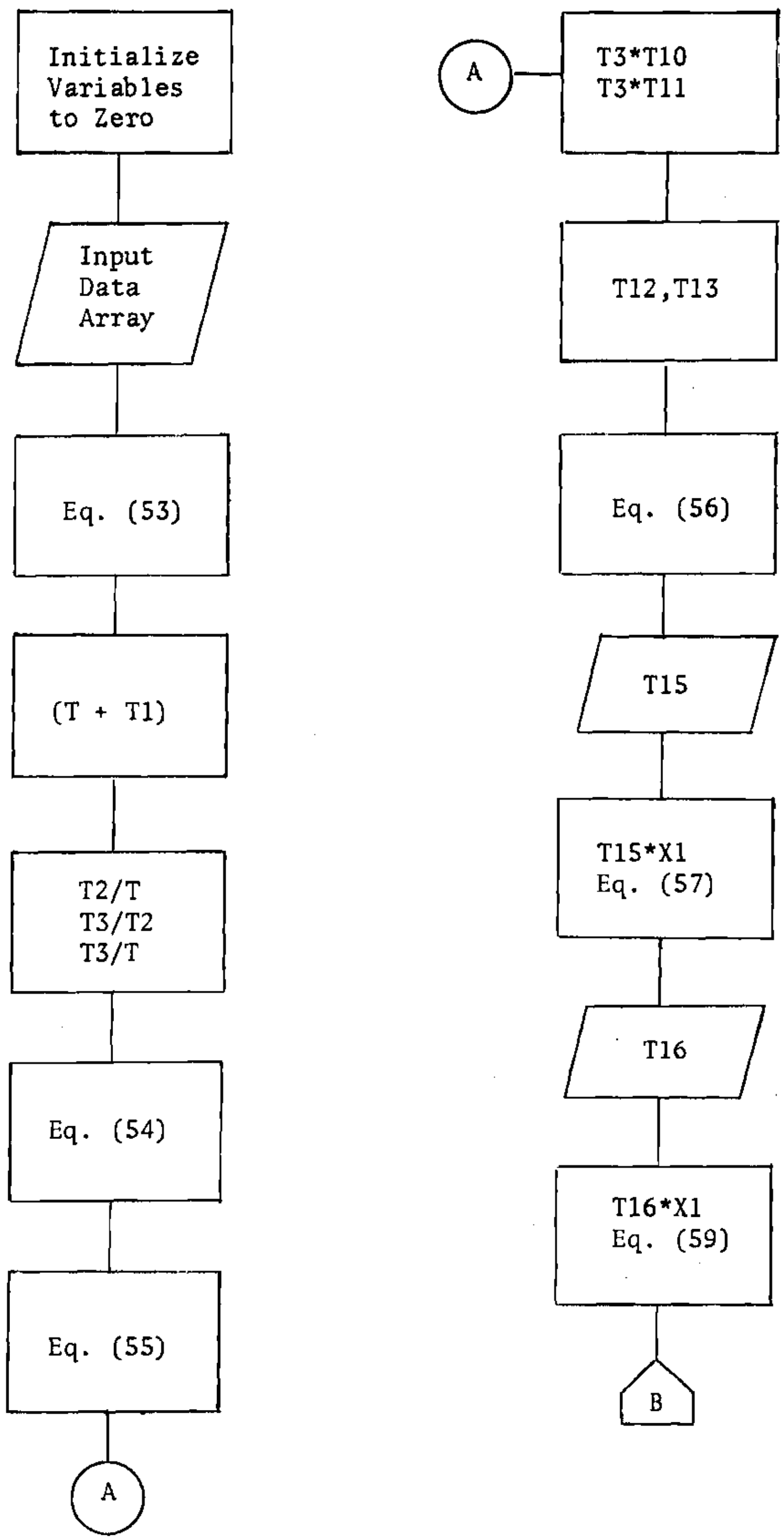


Figure 16. Transformation Model Logic Diagram

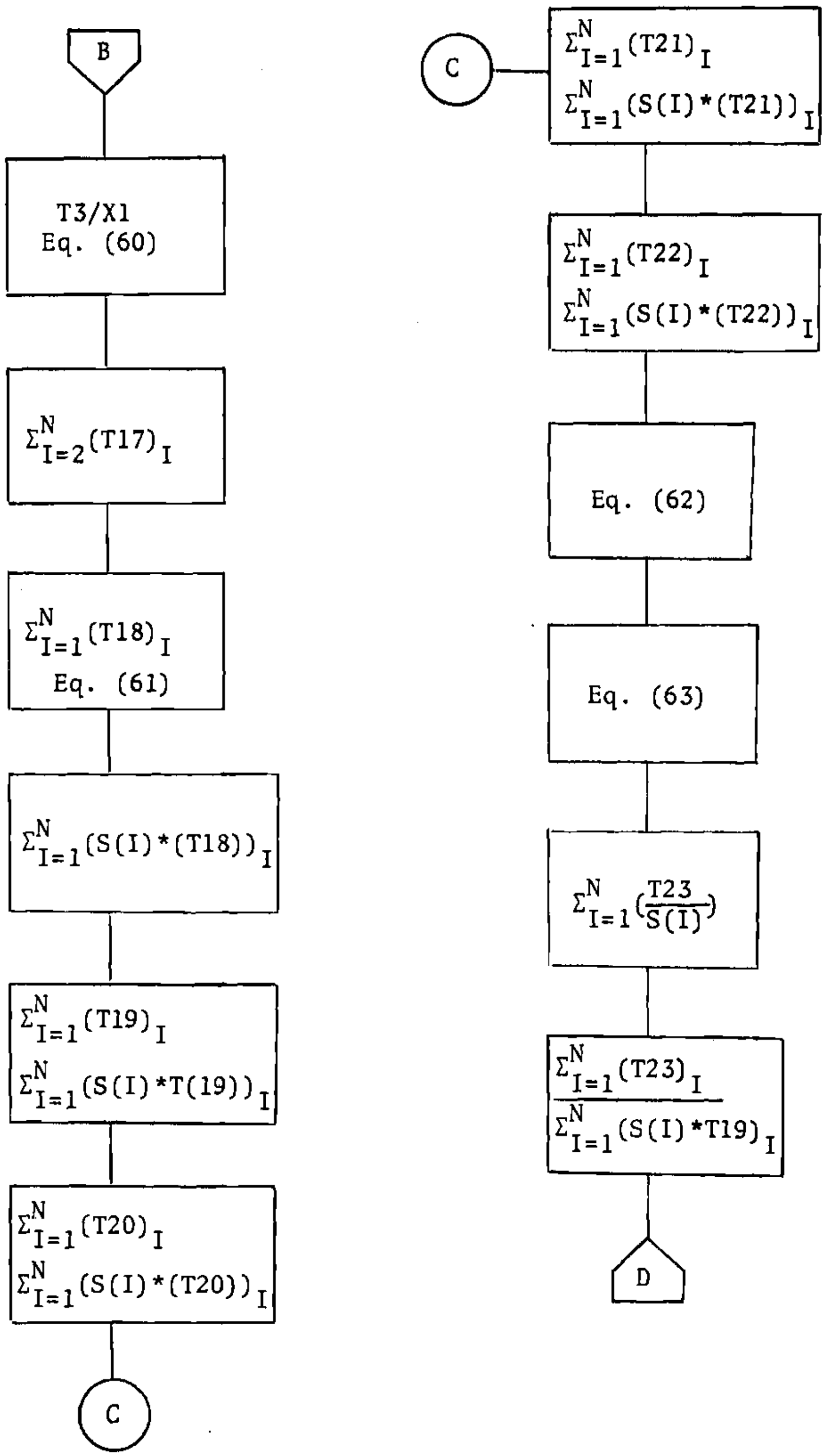


Figure 16. Continued

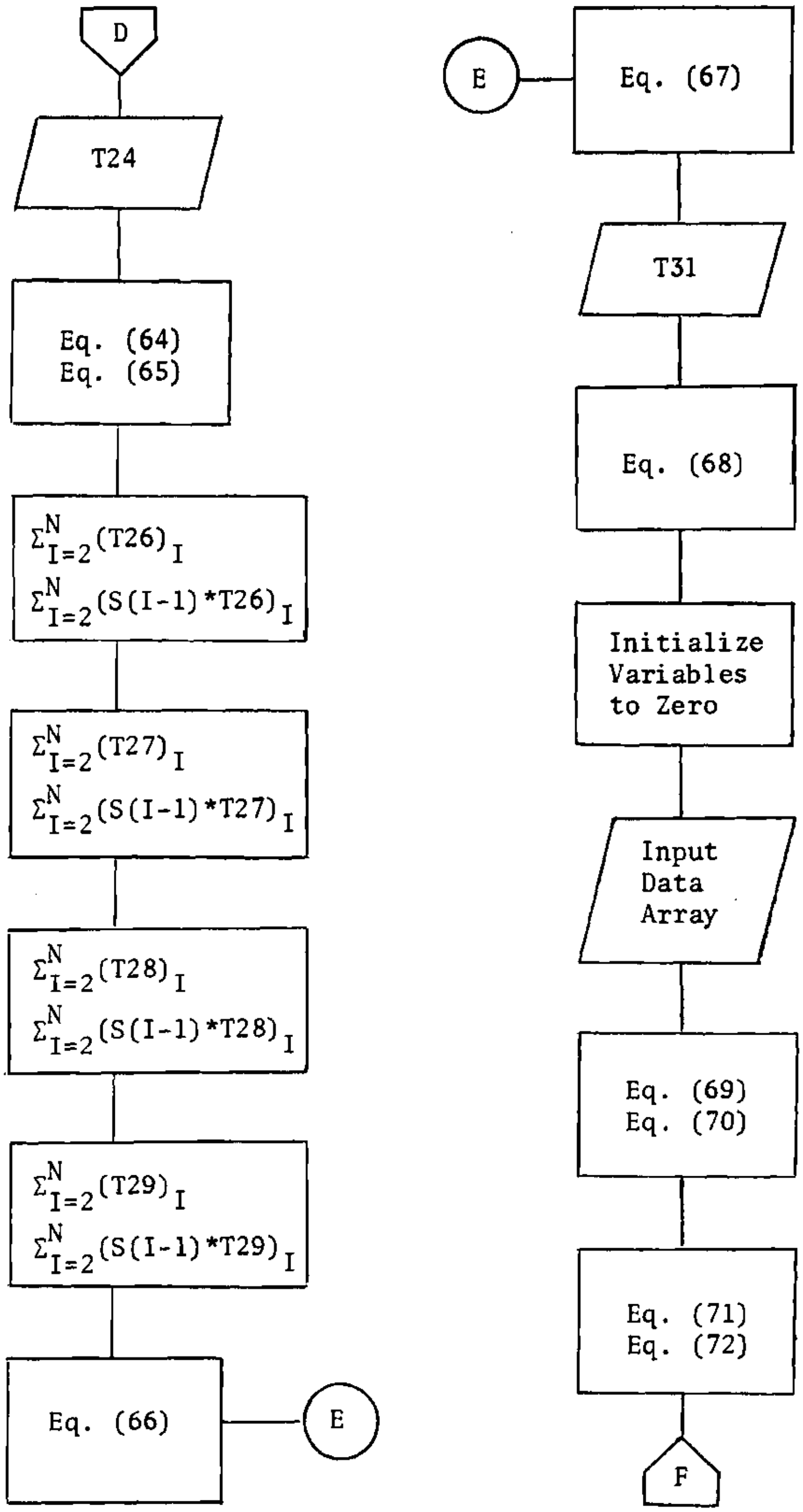


Figure 16. Continued

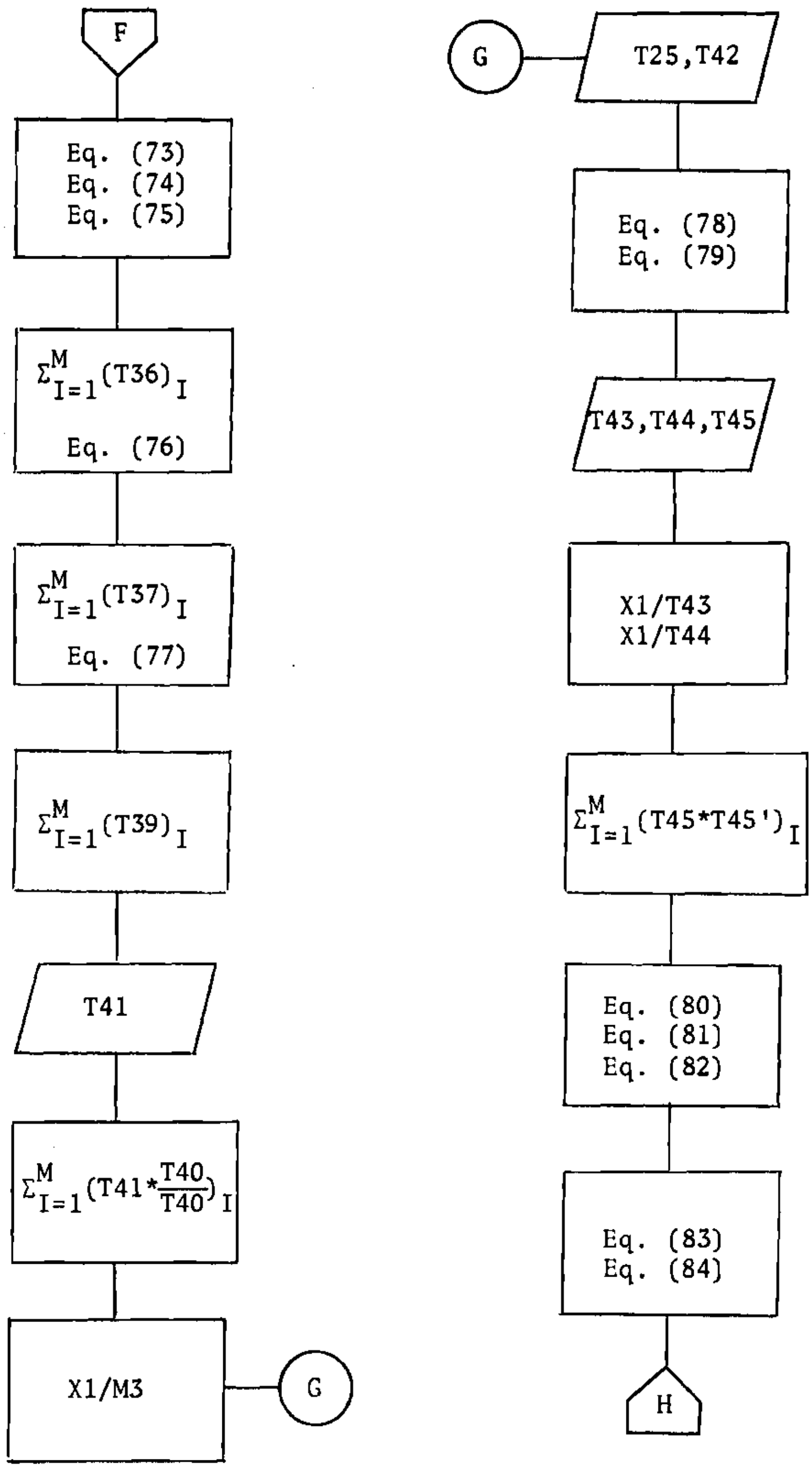


Figure 16. Continued

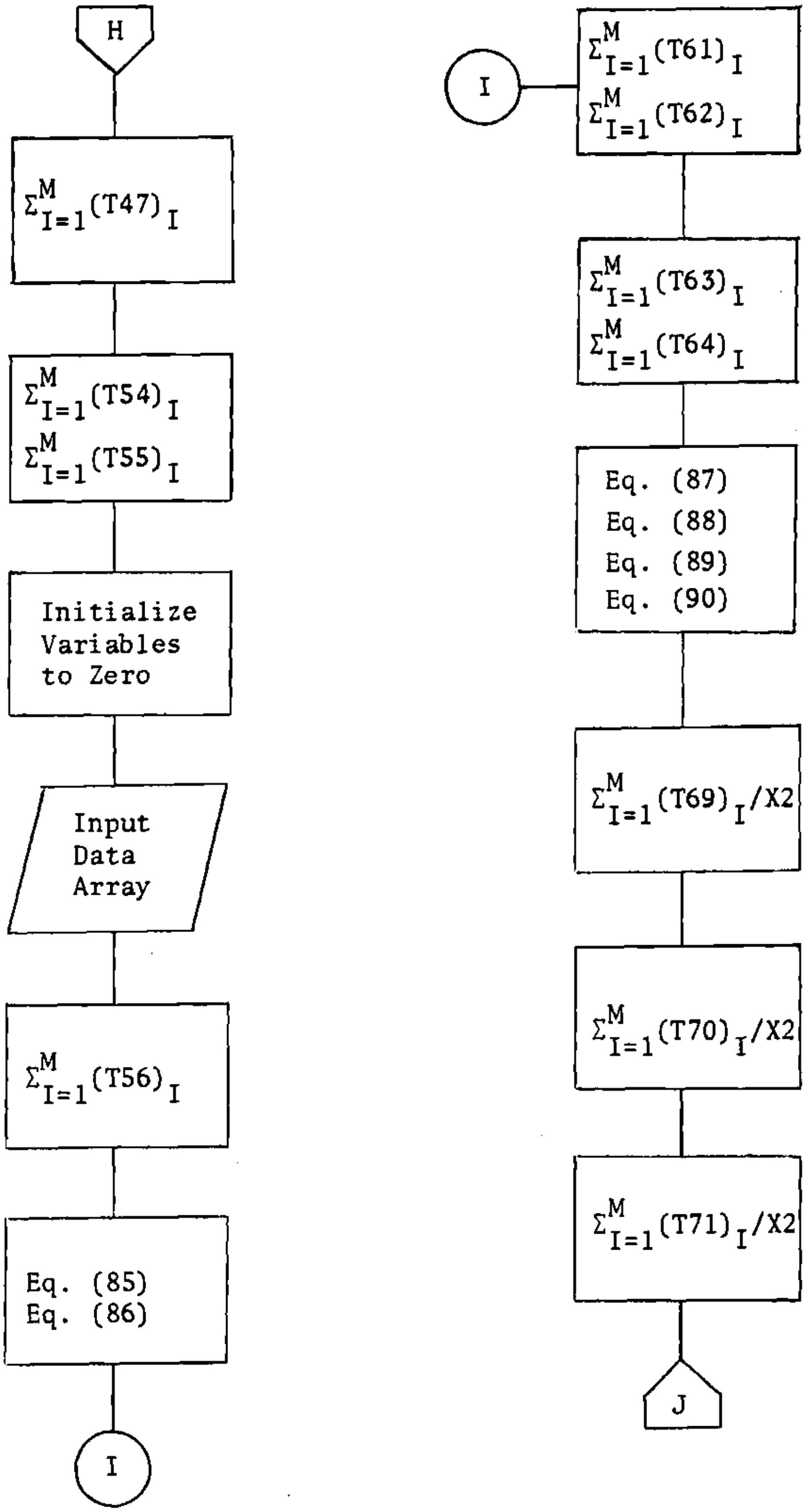
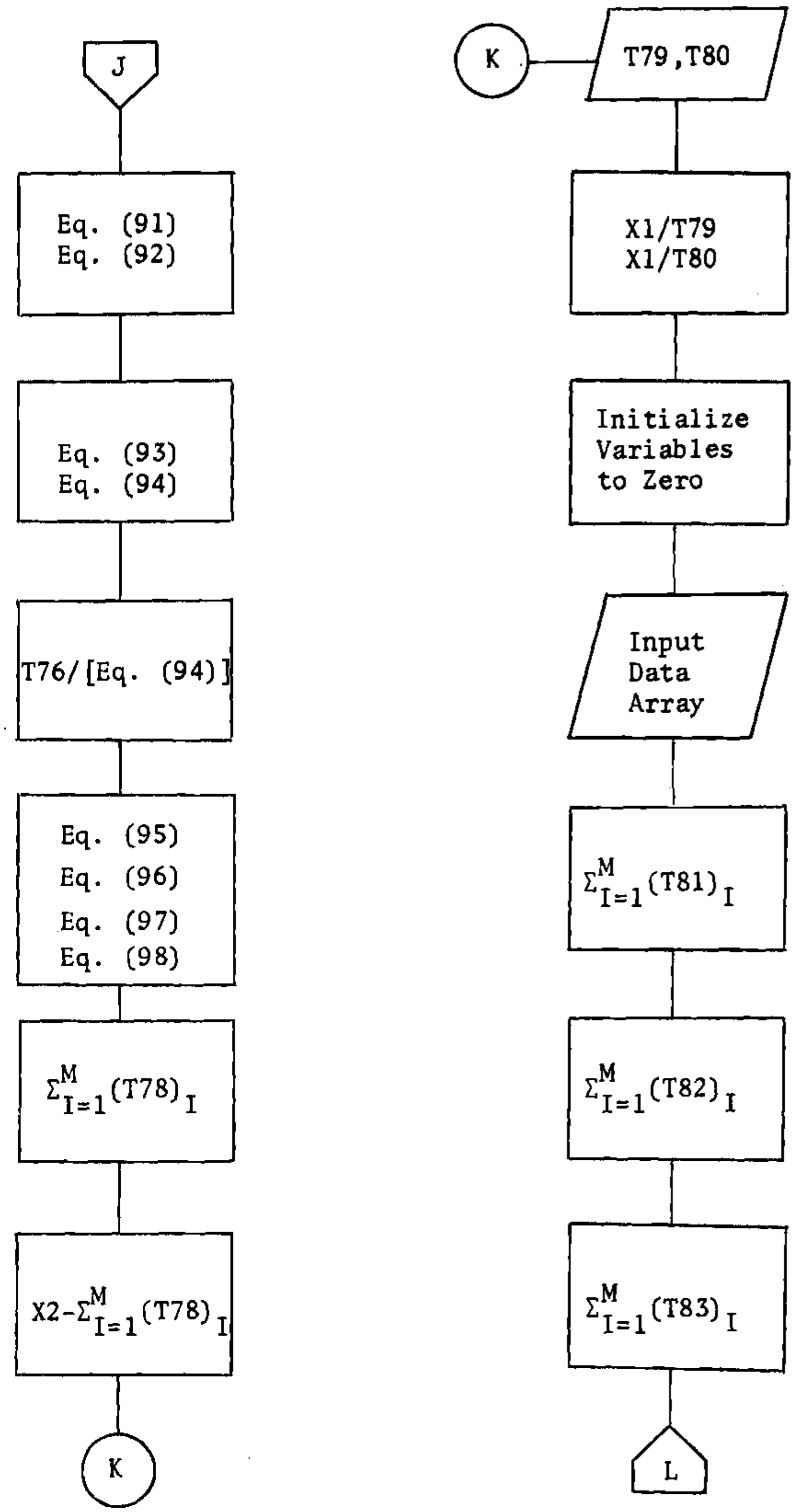


Figure 16. Continued



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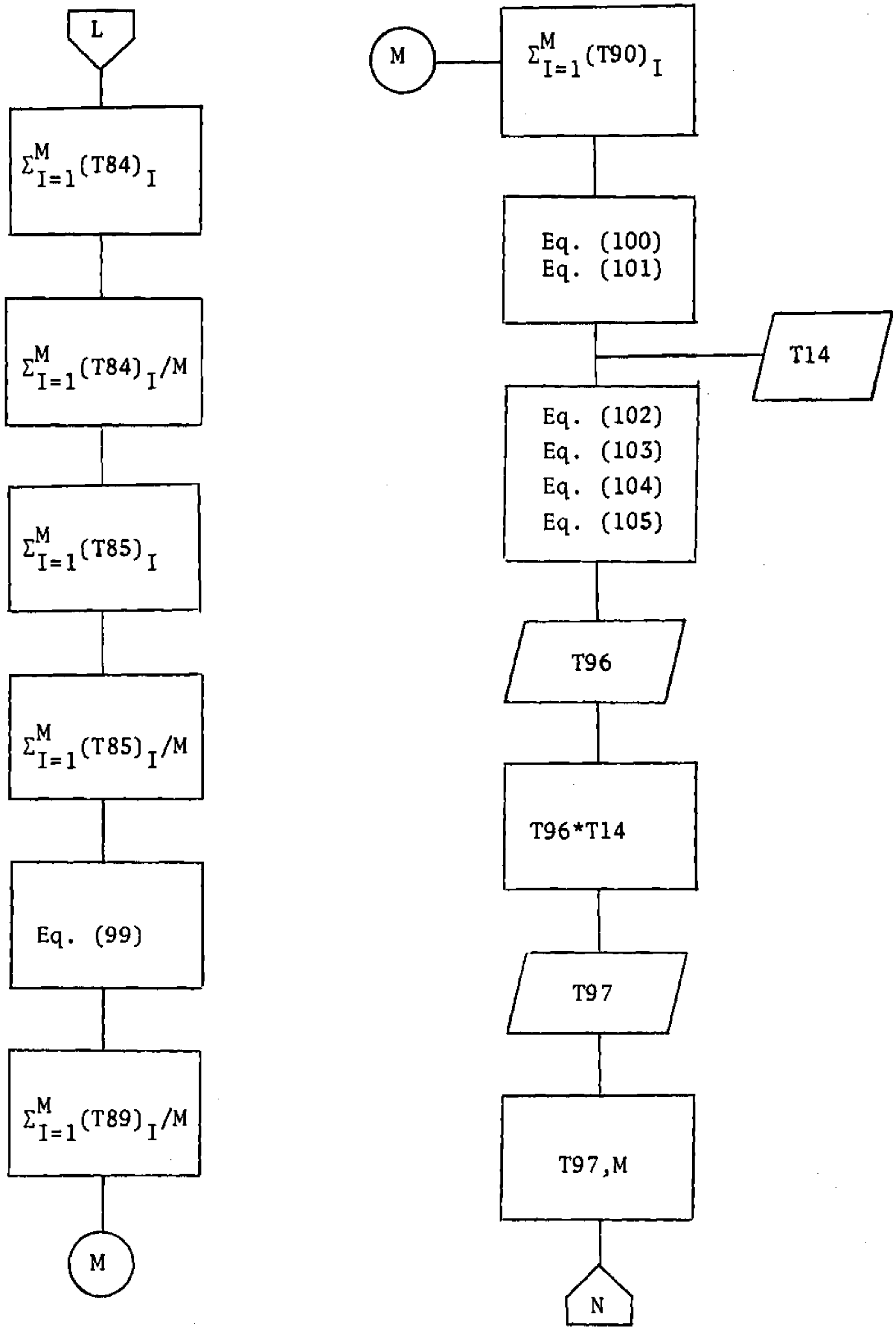

Figure 16. Continued

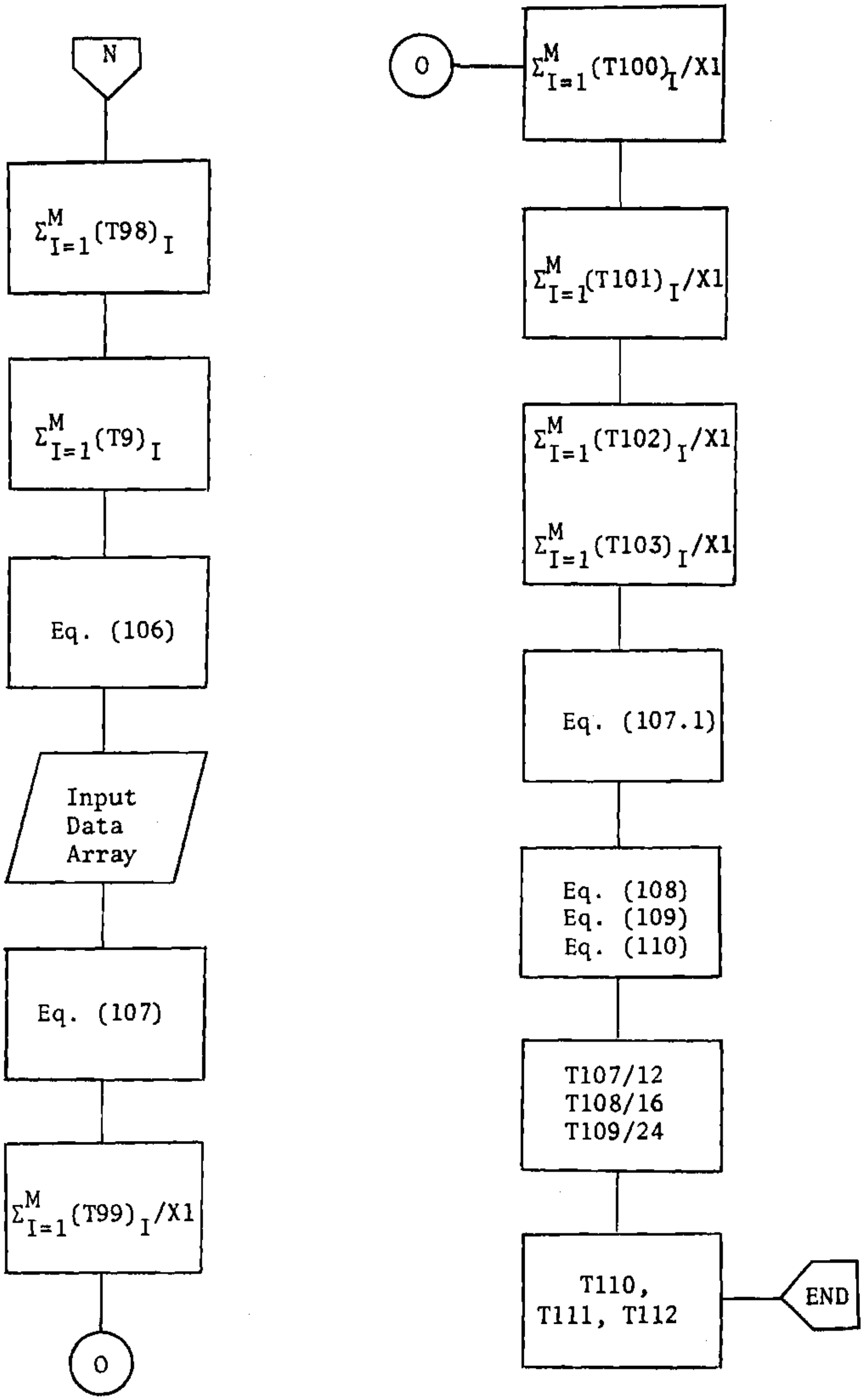

Figure 16. Concluded

therefore, the process of passing the parameters was terminated.

Knowledge Model

Mathematical Relationships

Data were inputted through a R × C array. The array contained the data for the mathematical expressions which represented the knowledge model. It was intended to demonstrate that the variables in the knowledge subsystem were measurable with this collection of mathematical equations. Equations were derived representing both process knowledge and content knowledge. Also the value of both major variables were calculated. These data were collected from the same chronological time period.

R = The number of departments in the university system

C = 18 column data vector

C1 = Department M, which identified the data vector for each department

C2 = The total number of principles offered by each department for state N

C3 = The total number of credit hours offered by each department for state N

C4 = The total student population in each department for state N

C5 = The average number of credit hours registered by a student in department M for state N

C6 = The number of faculty in each department for state N

C7 = The average number of credit hours taught weekly by a faculty member in department M for state N

C8 = The total number of courses offered by each department for state N

C9 = The number of grade A given to students in department M for state N

C10 = The number of grade B given to students in department M for state N

C11 = The number of grade C given to students in department M for state N

C12 = The number of grade D given to students in department M for state N

C13 = The number of grade F given to students in department M for state N

C14 = Total dollar market value of type 1 knowledge content in department M for state N

C15 = Total number of hours worked on type 2 knowledge content in department M for state N

C16 = Total dollars for type 3 knowledge content in department M for state N

C17 = Total number of hours worked on type 4 knowledge content in department M for state N

C18 = Total number of hours worked on type 5 knowledge content in department M for state N

The mathematical relationships that follow represented a subset of the equation set in the simulation model. They were the most important equations, and that was the reason for selecting them.

1. Summed down the column vector, C2, the total number of principles for the entire university system was given by

$$\sum_{I=1}^{M} (K)_I \ , \tag{111}$$

where I = 1,...,M was the number of departments in the university system.

2. It was important to measure the number of principles to students for each department. This calculation was accomplished by the ratio

$$\sum_{I=1}^{M} (K/K1)_I \ . \tag{112}$$

Equation (112) could be varied for a system-wide ratio of the number of principles to students,

$$\sum_{I=1}^{M} (K)_I \Big/ \sum_{I=1}^{M} (K1)_I \ . \tag{113}$$

3. The number of students receiving each principle in department M for state N was given by

$$\sum_{I=1}^{M} [(K/K2)*K3*(K1/K)]_I \ . \tag{114}$$

This equation was constructed similar to the equations in the transformation simulation model. It was a variation of the measure, but constructed to achieve a significant criterion.

4. A straightforward ratio was formulated to calculate the number of principles per faculty member in department M for state N.

$$\sum_{I=1}^{M} (K/K4)_I \tag{115}$$

Then another calculation was derived which determined the average number of principles taught by each faculty member in department

M for state N,

$$\sum_{I=1}^{M} \left[(K/K2)*K5\right. . \qquad (116)$$

Equations (115) and (116) demonstrated the interaction of faculty with the knowledge subsystem.

5. Two more ratio equations were calculated:

$$\sum_{I=1}^{M} (K/K2)_I \qquad (117)$$

was the number of principles per credit hour in department M for state N, and

$$\sum_{I=1}^{M} (K/K6)_I \qquad (118)$$

was the number of principles per course in department M for state N.

6. The next mathematical equation was a rough derivation of the percent of the total principles learned by the students in department M for state N. This derivation included the grade a student received for a course, and the number of principles specified in the course. Let

$$K12 = \sum_{I=1}^{M} (K7*1 + K8*.9 + K9*.8 + K10*.7 + K11*.6)_I \qquad (119)$$

which was the overall percentage of the principles learned by the students. Given K12 then the number of knowledge units learned by the students in department M for state N was given by

$$\sum_{I=1}^{M} [K12*(K/K2)*K3]_I \; . \qquad (120)$$

Equation (120) was a rough measure of the knowledge acquired by students. It was intended to demonstrate that a measure could be derived but not to be adopted for evaluating student performance. Other variables should be considered in this calculation.

7. Value overlays the knowledge subsystem just the same as any other subsystem. The next series of equations represented the value of knowledge content: type 1, 2, 4, and 5. The first equation in this series represented the value of type 1 knowledge content for the university system,

$$\sum_{I=1}^{M} (K13)_I \; . \qquad (121)$$

Second in the series was

$$\sum_{I=1}^{M} (K15*K14*1.1)_I \; , \qquad (122)$$

which represented the content value of type 2 knowledge. The multiplier was used to compensate for relief time which was a common factor in calculating labor costs. Type 4 knowledge content value, which was the value of laboratory preparation, was given by

$$\sum_{I=1}^{M} (K16*K14*1.2)_I \quad . \tag{123}$$

This multiplier included not only relief time compensation but also part-time personnel costs for laboratory preparation.

The final equation in this series calculated the value of a lecture which incorporated verbal and written communication. Type 5 knowledge content value was given by

$$\sum_{I=1}^{M} (K17*K14)_I \quad . \tag{124}$$

8. Given equations (121), (122), (123), and (124) the derivation for the value of both knowledge content and process could be completed. The additional value of a credit hour was included to give a better measure of the value of knowledge in the system. The total knowledge content and process value was equated

$$\sum_{I=1}^{M} [(K13 + K15*K14*1.1 + K16*K14*1.2 + K17*K14) + (K2*K18)]_I \tag{125}$$

in each department M for state N.

Equations (111) through (125) represented the simulation model of the knowledge subsystem. These equations were limited, because observable variables were utilized to derive the equations, and the unobservable were held constant. Incorporating some of the constant variables will be recommended.

Operational Logic

Figure 17 describes the logical structure of the simulation model. There were no parameters passed to the simulation model; however, the logic interrelated the variables of the transformation subsystem. Namely, the student and faculty flow variables interacted. Also there were no parameters passed to any of the following simulation models.

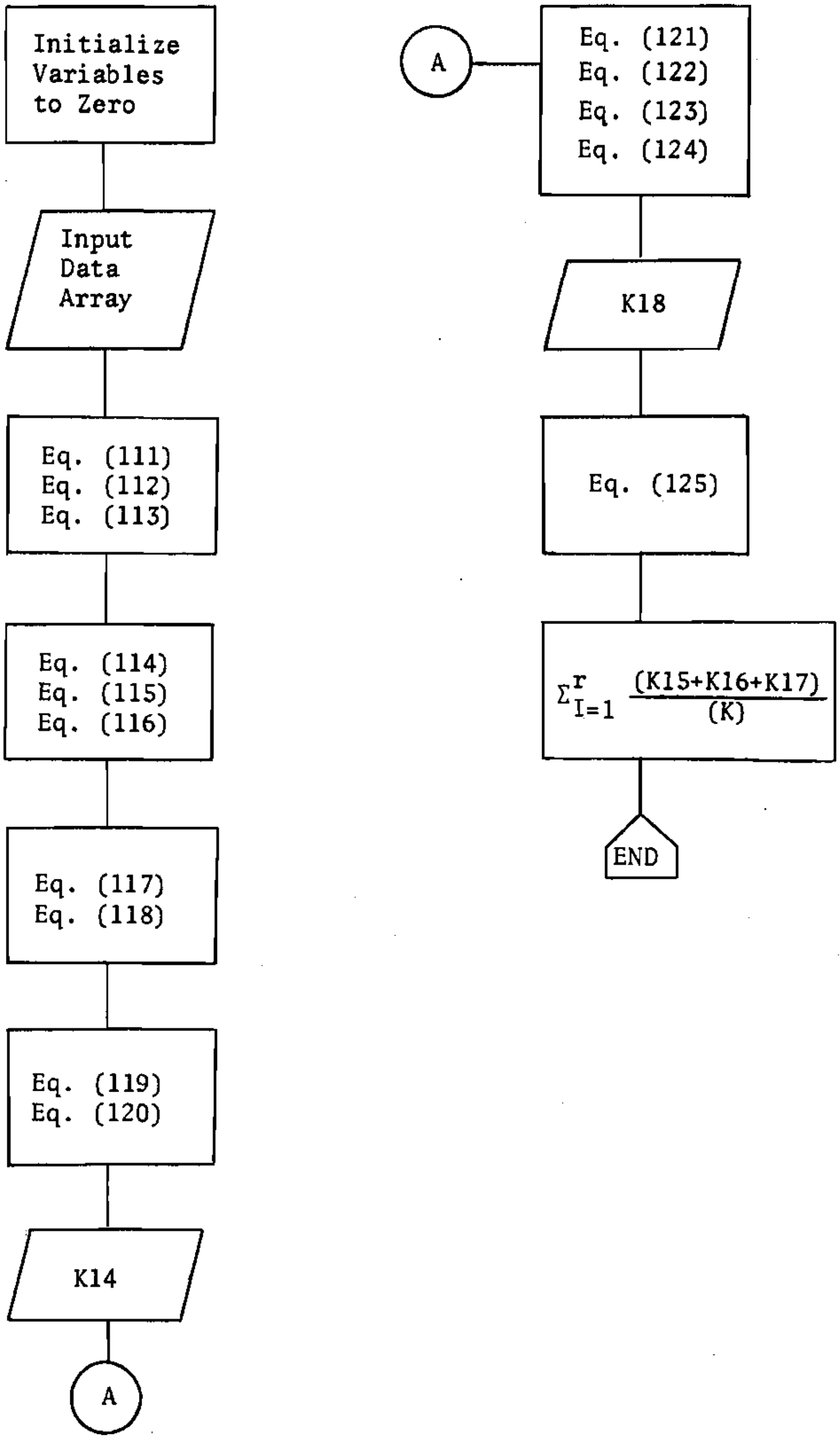

Figure 17. Knowledge Model Logic Diagram

Communication Subsystem

Mathematical Relationships

Data were inputted to the communication simulation model by a R × C data array. These data were manipulated by five primary summation equations. One loop equation summed every column vector for a certain number of rows. Every row vector represented the data for a block in the student and faculty flow models, and the seven organizational classes which were modeled. There are fifteen blocks or row vectors for the student flow, eight row vectors for the faculty flow, and seven row vectors for the organizational classes. After one primary summation equation the other mathematical expressions were repetitive; therefore, only one iteration of the summation equation is described.

These data were collected in the same chronological time period. All the data collected for this simulation model were approximated, because there were no records of data for this subsystem.

R = The total number of row vectors in the array, which equaled 29. Organizational class two was a zero row vector

C = 17 column data vectors

C1 = The average number of communication-network nodes for state N

C2 = The average number of communication nodes for state N

C3 = The frequency with which device 1 was used for state N

C4 = The frequency with which device 2 was used for state N

C5 = The frequency with which device 3 was used for state N

C6 = The frequency with which device 4 was used for state N

C7 = The frequency with which device 5 was used for state N

C8 = The average efficiency of each communication for state N

C9 = The number of late communications for state N

C10 = The average number of days between sending and receiving a communication for state N

C11 = The average number of circuit networks for state N

C12 = The total number of receivers of communication for state N

C13 = The total number of senders of communication for state N

C14 = The average number of feedback communications for state N

C15 = The average percentage of noise in communication for state N

C16 = The dollar value of a successful communication

C17 = The dollar value of a loss in communication

The main summation equation described represented the row vectors one through six, which simulated the student input communication. One could look back to the student physical flow model and observe the blocks SP1 through SP6 which were a pictorial model of the student input communication.

1. Defined a column vector, L(J) for J = 1,...,17 which summed across the rows I = 1,...,6. A(I,J) were the data elements which were manipulated by this equation

$$L(J) = L(J) + \sum_{I=1}^{6} A(I,J) \ . \tag{126}$$

For example, L(1) represented a summation of all the average communication-network nodes, C, for student input. Every column vector J was summed across I rows in a main summation equation.

2. The total number of communication nodes for student input was given by

$$L(2)*L(13)/6 \, , \tag{127}$$

where $L(2) = \sum^{6} C8$ and $L(13) = \sum^{6} C1$.

3. The overall average efficiency of input communications was given by

$$L(8)/6 \, , \tag{128}$$

where $L(8) = \sum^{6} C9$, and another ratio,

$$L(9)/L(13) \, , \tag{129}$$

where $L(9) = \sum^{6} C10$, calculated the overall average timing index of student input communication.

4. The overall average timeliness of a student input communication was represented by the average

$$L(10)/6 \, , \tag{130}$$

where $L(10) = \sum^{6} C11$.

5. To average the total number of circuit networks for student input communication, the equation

$$L(11)*L(12)/6 \, , \tag{131}$$

where $L(11) = \sum^{6} C12$ and $L(12) = \sum^{6} C2$, was used.

6. Another typical expression was

$$L(14)*L(12) \, , \tag{132}$$

where $L(14) = \sum^{6} C13$, which totaled the number of feedback communications in the student input.

Equations (127) through (132) were the standard mathematical relations derived for the communication model. These same equations, except for the number of iterations, were repeated for each set of row vectors defined in the simulation model. Four sets of row vectors were defined by the remaining four summations.

7. A column vector was defined, K(J), for J = 1,...,17 which summed across the rows I = 8,...,11. A(I,J) was the data array in the R × C array defined by the summation equation,

$$K(J) = K(J) + \sum_{I=8}^{11} A(I,J) \ . \tag{133}$$

Equation (133) was derived to evaluate the communication within the student transformation process. SP7, SP8, SP9, and SP10 of the student physical flow model were defined by these four row vectors.

8. A third column vector was defined, M(J), for J = 1,...,17 which summed across the rows I = 12,...,15. The elements A(I,J) were in the R × C data array defined by this summation equation,

$$M(J) = M(J) + \sum_{I=12}^{15} A(I,J) \ . \tag{134}$$

Summing across the rows I = 12,...,15 manipulated the data to produce the criteria for evaluating the output communication of the transformation subsystem.

9. A fourth column vector was defined, N(J), for J = 1,...,17 which summed across the rows I = 16,...,23. The data array elements A(I,J) were manipulated into the output criteria by

$$N(J) = N(J) + \sum_{I=16}^{23} A(I,J) \tag{135}$$

which evaluated the faculty communication flow.

10. The fifth column vector was defined as, O(J), for J = 1,...,17 which summed across the rows I = 24,...,r. Data elements, A(I,J) represented the data which were summed to represent the organizational communication component. The summation,

$$O(J) = O(J) + \sum_{I=24}^{r} A(I,J) \ , \tag{136}$$

was calculated to evaluate the organizational component of the communication subsystem.

Five summation equations were defined in the communication simulation model. Equations (126) through (133) demonstrated the mathematical relationships which were repeated for every summation equation.

Operational Logic

All the mathematical expressions were shown in the logic diagram. One could see that the equations were repetitive and were dependent upon the five summation equations. Figure 18 shows the operational logic of the communication simulation model. There were no entering parameters to this simulation model nor parameters which

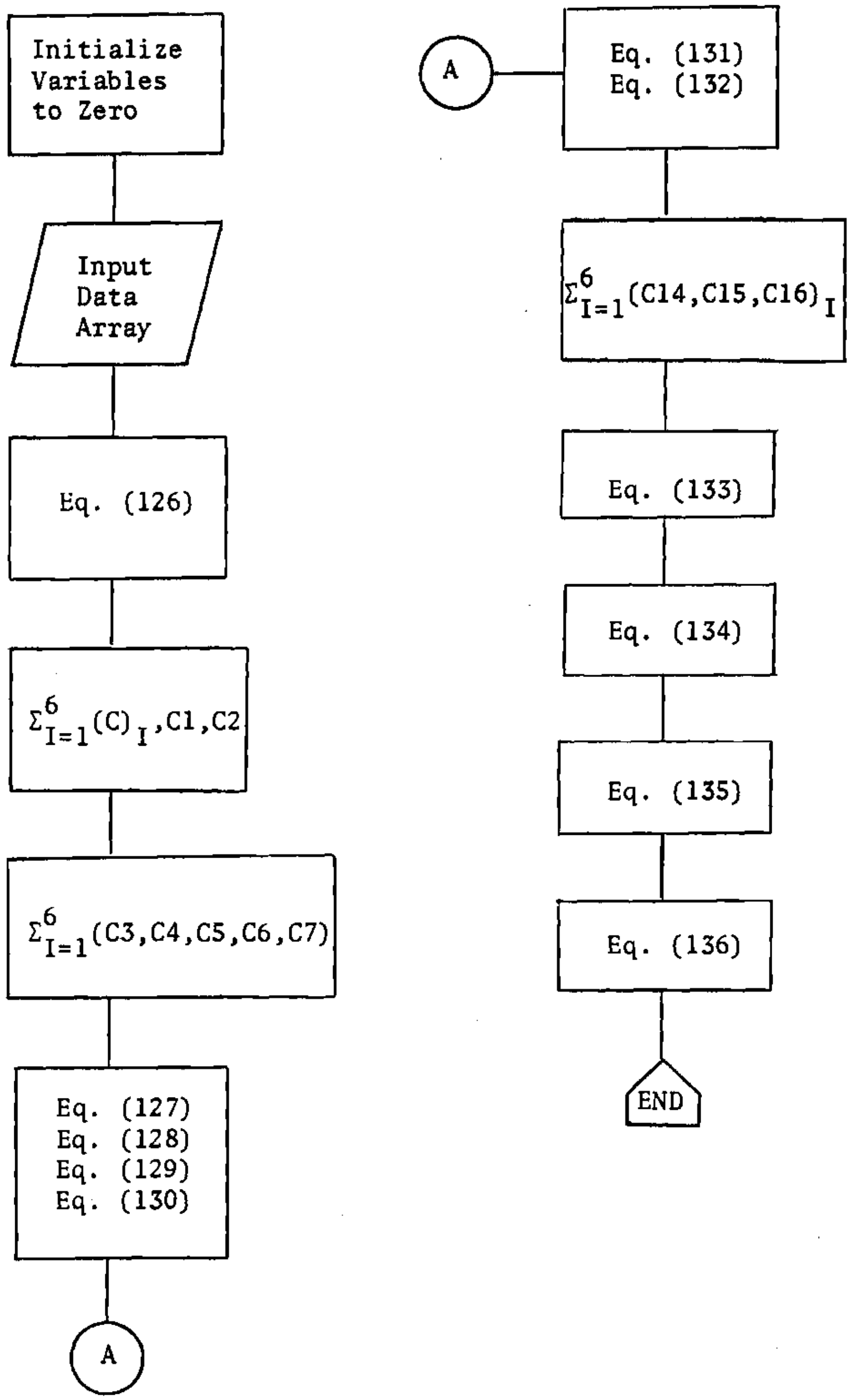

Figure 18. Communication Model Logic Diagram

left it.

Value Model

Mathematical Relationships

Both linear and nonlinear mathematical expressions were derived in the value simulation model. Equations were formulated to represent every subsystem model, because value was the common integrator in the university system. Variables from every subsystem were transplanted to this simulation model, and the equations demonstrated the strong interrelationships of value in the university system.

These mathematical expressions represented one's view of the university system. For the initial attempt at deriving representative equations, they were the best for evaluating any university system.

Data were inputted in a R x C array. Most of the data were transformed from earlier collected data to the present form of this array. It was required that the data be collected from the same chronological time period.

R = The number of grids 1,2,...,r considered for evaluating the university system value

C = 25 column data vectors

C1 = Grid number; which identified the row vector for grid r

C2 = The dollar market value of an acre of land

C3 = The replacement value per square foot of building volumetric space for grid r

C4 = The total number of volumetric square feet of building space for grid r

C5 = The average chronological age of the buildings for grid r

C6 = The replacement value per unit of equipment for grid r

C7 = The total number of equipment units for grid r

C8 = The average chronological age of the equipment units for grid r

C9 = The total market value of the people in grid r

C10 = The population of people in grid r

C11 = The total market value of people in the organization for grid r

C12 = The total overhead of the organization for grid r

C13 = The average cost per student to enroll in system for grid r

C14 = The student population in grid r

C15 = The total number of hours dropped by student for grid r

C16 = The average hourly market value of a faculty member for teaching in grid r

C17 = The dollar value of research output produced for grid r

C18 = The total hours absent by students in grid r

C19 = The average market value for graduating student population in grid r

C20 = The total number of graduating students in grid r

C21 = The total number of hours worked per principle for grid r

C22 = The average value per principle for grid r

C23 = The total number of principles taught for grid r

C24 = The total value of successful communication for grid r

C25 = The total value of communication loss for grid r

1. The single-payment compound-amount series was equated to

$$X1 = (1 + V1) \, , \qquad (137)$$

with an interest of V1 for a one year interest period, and

$$X2 = (1 + V1)^{V2} \tag{138}$$

for V2 interest periods. Equations (137) and (138) were used to find the future sum, V2 annual interest periods hence, equal to the compound amount of the present principal sum.

2. Given X1 and X2 the market value of land was given by

$$\sum_{I=1}^{r} (X2*V3)_I \tag{139}$$

for grid r, which could be further expanded into the market value per square foot of land for grid r by

$$\sum_{I=1}^{r} (X1*V3)_I/43560 \ . \tag{140}$$

For equation (140), X1 = X2 because V2 was equated to 1.

3. The value for building volumetric space was calculated by a straight-line depreciation method. For a building the salvage value was assumed zero after a life of fifty years. Therefore, the value of the building volumetric space was

$$Z1 = \sum_{I=1}^{r} [(V4*V5*X2) - \left((V4*V5*X2)/50\right)*V6]_I \tag{141}$$

for grid r. Let Z1 equal equation (141) which will be used in upcoming equations. Dividing through equation (141) by the total building volumetric space for grid r,

$$\sum_{I=1}^{r} [(V4*V5*X2) - \{(V4*V5*X2)/50\}*V6]_I \Big/ V5 \ , \tag{142}$$

the value of a square foot of building volumetric space could be measured.

4. Straight-line method of depreciation was applied to measure the value of the equipment inventory. The estimated life of a unit of equipment was ten years and the salvage value was zero. A solution to find the value of the equipment inventory was

$$Z2 = \sum_{I=1}^{r} [(V7*V8*X1) - \{(V7*V8*X1)/10\}*V9]_I \tag{143}$$

for grid r. Let Z2 equal equation (143) for use in upcoming equations.

5. The market value of the labor force was given by

$$\sum_{I=1}^{r} (V10*X2)_I \tag{144}$$

for grid r. Dividing by the population of the labor force for grid r gave

$$\sum_{I=1}^{r} (V10*X2/V11)_I . \tag{145}$$

Equation (145) represented the average market value of the labor force in grid r. Continuing to breakdown the labor force value one could find the hourly market value of the labor force for grid r by

$$\sum_{I=1}^{r} [(V10*X2)/(40*V11*50)]_I \ , \tag{146}$$

assuming a forty-hour work week and fifty-week work year.

6. Combining equations (139), (141), (143), and (144), a profile of the facilities subsystem by grid was given by

$$\sum_{I=1}^{r} [(X1*V3) + Z1 + Z2 + (V10*X2)]_I \ . \tag{147}$$

Equation (147) was used to determine which grids were positive value centers or negative value centers.

7. The people in the organization were assigned to buildings; therefore, their value was assigned to the grid in which the building occupied. Based upon this assignment rule the organizational value could be determined by

$$\sum_{I=1}^{r} \left((V12 + V13)*X2\right)_I \tag{148}$$

for grid r. Generally the organizational subsystem occupied a small number of grids in comparison to all the grids of the value model.

8. A process value was derived from the interaction of the following subsystems: facilities, transformation, and knowledge. This derivation represented the value to process students in

the university system. Given the value equations from the facilities, transformation, and knowledge subsystems, the process value was

$$Z4 = \sum_{I=1}^{r} [(X2*V3) + Z1 + Z2 + (V10*X2) + Z3]_I \ , \tag{149}$$

where

$$Z3 = \sum_{I=1}^{r} [(V15*V16)*X2 + (V17*V18)*X2]_I \ . \tag{150}$$

Equation (150) represented the student input value for tuition in the first part, and the knowledge content and process value in the second part. Another assignment rule was given for this derivation. Students were assigned to the grid where their department resided, also faculty were assigned the same way. With this assignment rule the process value, equation (149), could be determined for grid r.

Given the process value equation, an average value of a student for grid r was given by

$$\sum_{I=1}^{r} [\big((X2*V3) + Z1 + Z2 + (V10*X2) + Z3\big)/V16] \ . \tag{151}$$

Dividing by the total number of grids, an average value of a student in the university system was

$$\sum_{I=1}^{r} [\big((X2*V3) + Z1 + Z2 + (V10*X2) + Z3\big)/V16]/r \ . \tag{152}$$

9. The value for dropping a course was

$$Z5 = \sum_{I=1}^{r} [\big((V19*V20)*(1 + 2 + .1) + (V20*V21)\big)*X2]_I \tag{153}$$

for grid r. This derivation considered the student and faculty interaction. The multiplier was determined from the fact that the student dropping the course left vacant a slot in which another student could fill. In addition there was an overhead value which was assumed to be 10 percent. Summing Z5 over all the grids, a total system value for dropped courses was measured.

10. Finding the value of an absent student took a two-step derivation. Step one was to determine the absenteeism value for grid r by

$$\sum_{I=1}^{r} (V19*V22*X2)_I \ . \tag{154}$$

Once step one was calculated then step two could be derived by dividing through by the student population for grid r.

$$\sum_{I=1}^{r} \big((V19*V22*X2)/V16\big)_I \tag{155}$$

Equation (155) was the absenteeism value per student for grid r.

11. The uniform gradient-series financial model was applied to calculate the system's product value. After applying this financial model to the value subsystem, the following equation was the solution:

$$(V23 + V23*.1*11.4234*40*V24) \quad , \tag{156}$$

where the interest rate was 7 percent compounded annually, the annual salary growth was 10 percent, and the interest period was 40 years. Appendix A describes an application of the uniform gradient-series. Equation (156) broke down further to

$$V23(1 + .1*11.4234)*40*V24 \quad ,$$

which gave

$$V23*V24*(1 + .1*11.4234)*40.$$

Let

$$X3 = (1 + .1*11.4234)*40 \quad , \tag{157}$$

which was the uniform gradient-series multiplier in the calculation of product value.

Given X3, then the product value for grid r was

$$\sum_{I=1}^{r} (V23*V24*X3)_I \quad . \tag{158}$$

One must remember that the assignment rule for the student population was in effect; therefore, the product value could be calculated for grid r.

12. The product value equation was the output value of the process. The input value for the process was given by equation (149); therefore, a ratio of process value output to input was given by

$$\sum_{I=1}^{r} (V23*V24*X3)_I \Big/ \sum_{I=1}^{r} (X2*V3 + Z1 + Z2 + V10*X2 + Z3)_I \ . \qquad (159)$$

Summing the output value and input value over all the grids, resulted in a total system process value ratio of output to input.

13. It was assumed that knowledge content depreciated over a time period for an average student. With this assumption the total dollar for knowledge content was given by

$$\sum_{I=1}^{r} [(V17*V18*X2)*(1 - V25)]_I \qquad (160)$$

for grid r. Equation (160) was summed over all the grids to calculate the total dollar knowledge content value for the whole university system.

The hourly value of knowledge content excluded the assumption in its derivation for grid r,

$$\sum_{I=1}^{r} [(V18*X2)*(1/V26)]_I \ . \qquad (161)$$

Equation (161) represented the knowledge content value for one credit hour. It could be summed over all the grids for a total knowledge content hourly value for the system.

14. There were two equations representing the communication value. The first,

$$\sum_{I=1}^{r} (V27*X2)_I \ , \tag{162}$$

was for a successful communication, and

$$\sum_{I=1}^{r} (V28*X2)_I \tag{163}$$

was for a loss of communication. Adding equations (162) and (163) gave the communication value for grid r,

$$\sum_{I=1}^{r} \left((V27 + V28)*X2\right)_I \ . \tag{164}$$

Given the values for both types of communication, then the value ratio of a successful communication to a loss of communication was

$$\sum_{I=1}^{r} (V27*X2)_I \Bigg/ \sum_{I=1}^{r} (V28*X2)_I \ . \tag{165}$$

15. A logical endpoint to the value simulation model was a profile of the whole system. This final derivation included all the value equations of every subsystem. The first step in the derivation was to define Z7,

$$Z7 = \sum_{I=1}^{r} [(V15*V16 + (V17 * V18)*(1 - V25) + V27 + V28)*X2]_I$$

which was the value of the knowledge and communication subsystems for grid r.

Given Z7, it followed that the university system value was

$$Z6 = \sum_{I=1}^{r} [(X2*V3) + Z1 + Z2 + V10*X2 + (V12 + V13)*X2 + Z7]_I \tag{166}$$

for grid r. The total system value was a summation over all the grids:

$$\sum_{I=1}^{r} (Z6)_I \ . \tag{167}$$

Dividing (166) by the number of days in a school year, an estimated daily value of the university system was

$$\sum_{I=1}^{r} (Z6)_I/V14 \ . \tag{168}$$

Given the value of the university system, a simple output to input value ratio was given by

$$\sum_{I=1}^{r} (V23 * V24*X3 + V29)_I \Big/ \sum_{I=1}^{r} (Z6)_I \ . \tag{169}$$

Included in the output value portion was the value of the research (V29) in the university system. Research value was defined as a product of the university system.

A total system output to input value ratio was determined by summing over all the grids.

Rearranging equation (169), a difference expression could be derived. The difference value between the system output and input was given by

$$\sum_{I=1}^{r} (V23*V24*X3 + V29)_I - \sum_{I=1}^{r} (Z6)_I \quad . \tag{170}$$

This difference equation showed the grids as either positive value centers or negative value centers. One could sum over all the grids and calculate the difference value for the university system.

Operational Logic

Figure 19 shows the logical flow of the value simulation model. Most of the equations have been described in the preceding section because this simulation model was the critical common denominator of the university system. Parameters neither entered the model nor will leave it. The simulation cycle was completed, and this logic was linked to the land simulation model. If a two-year prediction was desired the simulation cycled another time.

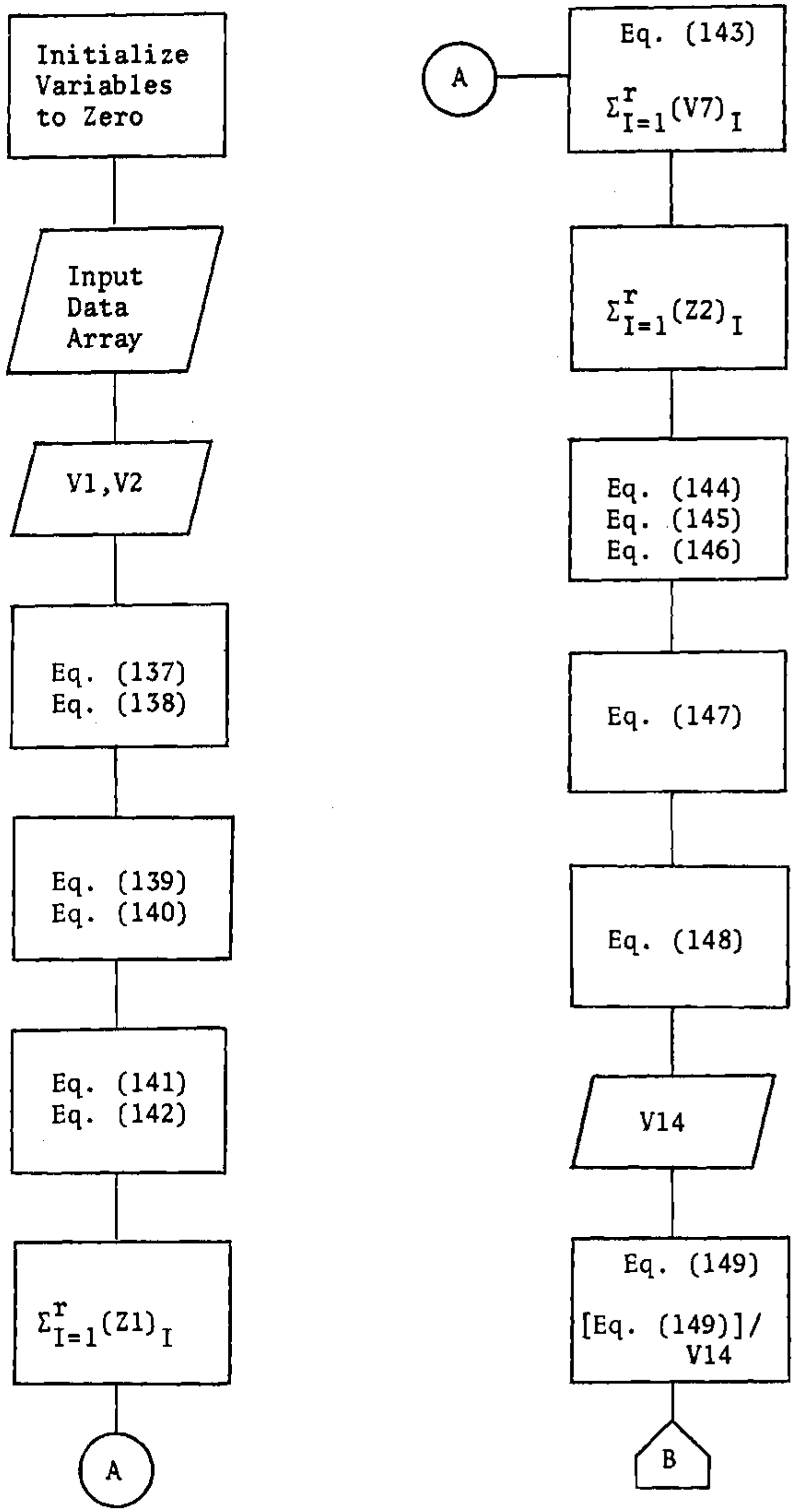

Figure 19. Value Model Logic Diagram

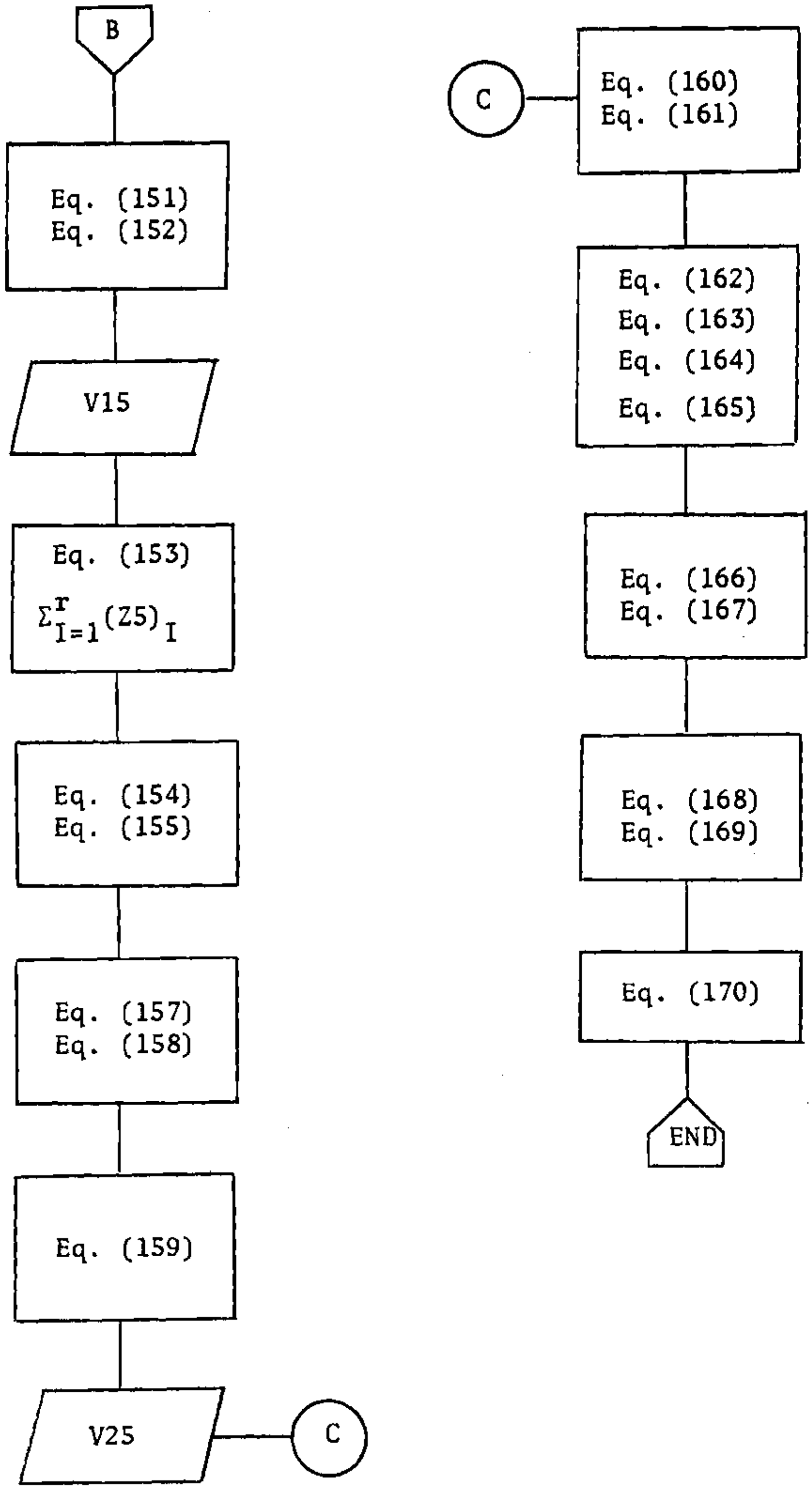

Figure 19. Concluded

Dynamics

Operational Logic

Overlaying the dynamic model on the whole university system required logical operations in each subsystem. The dynamic model did not have unique operational logic; consequently, a macro view of the logic in Figure 20 was substituted for a detailed flowchart.

In Figure 20 each subsystem was chained together to represent the whole system. The START block represented the front-end program which inquired about the time increment and type of evaluation desired. Blocks 1 through 9 have been presented in previous sections: 1-4 were facilities; 5 was organization; 6 was transformation; 7 was knowledge; 8 was communication; and 9 was value. Dynamics was integrated into each subsystem through a procedure which allowed one to increase, decrease, or keep the previous data for the next run. The data were brought into each model from a data file, which is the cylindrical symbol. After the subsystems were evaluated, one had three options to increase, decrease, or keep the same data. Once the option was applied to the data, it returned to the data file and would wait to be used on the next run.

Dynamics overlay the whole university system. It caused variables to change through time and provided the design for the evaluation of the whole system. This model completed the total system design and the simulation model of the university system.

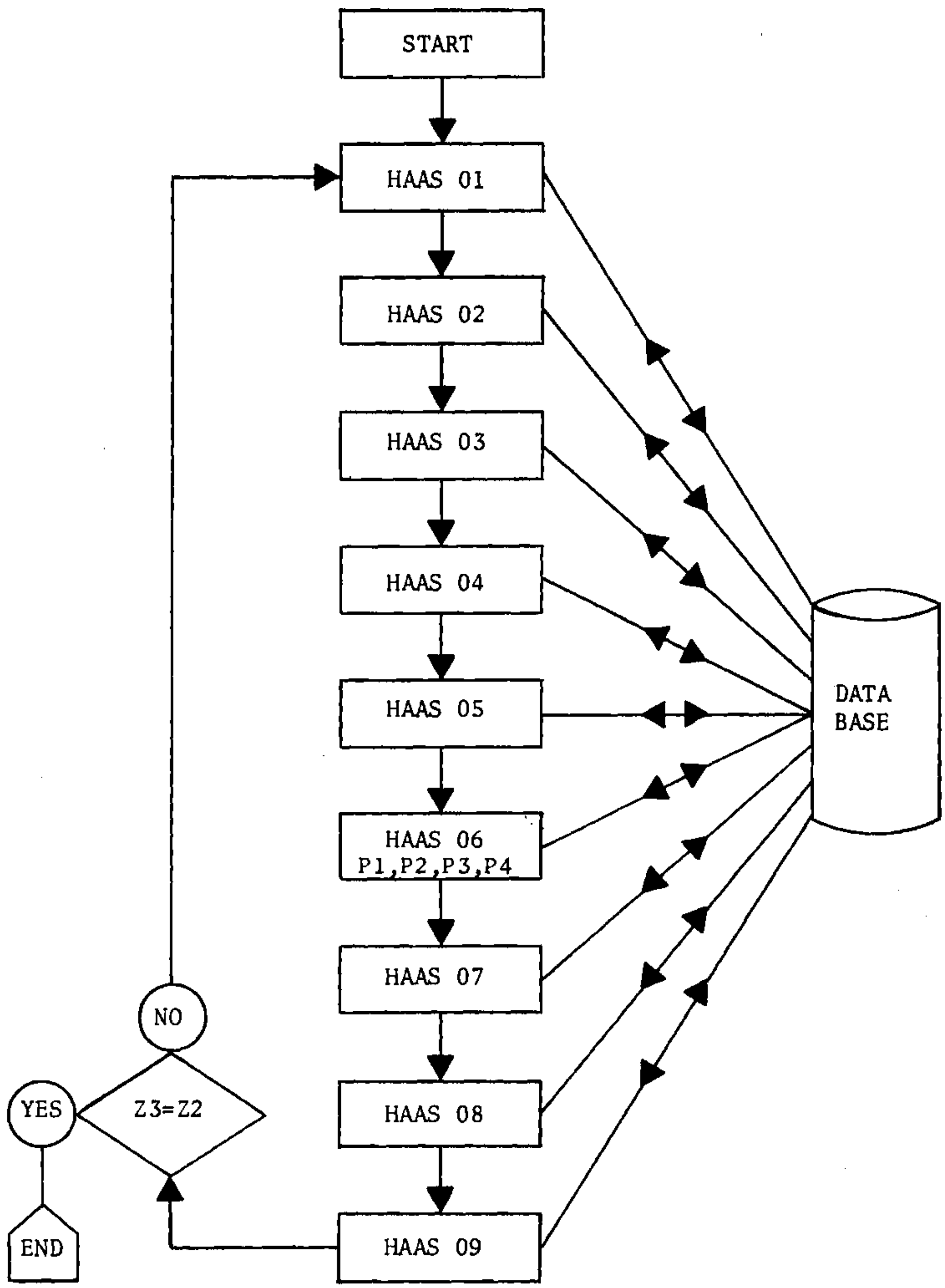

Figure 20. System Dynamics Model Logic Diagram

APPENDIX D

RATE OF CHANGE OF ENROLLMENT IN ALL INSTITUTIONS OF HIGHER EDUCATION

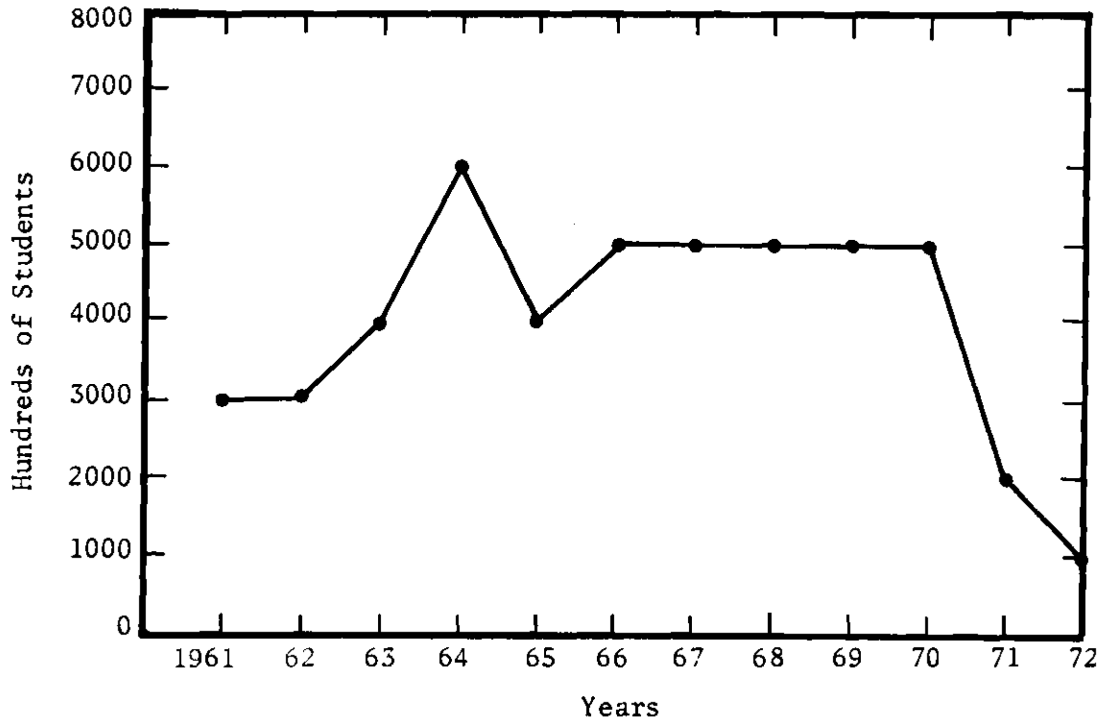

Figure 21. Rate of Change of Enrollment in All Institutions of Higher Education. (Source: Projection of Educational Statistics to 1981-82, National Center for Educational Statistics, 1972.)

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